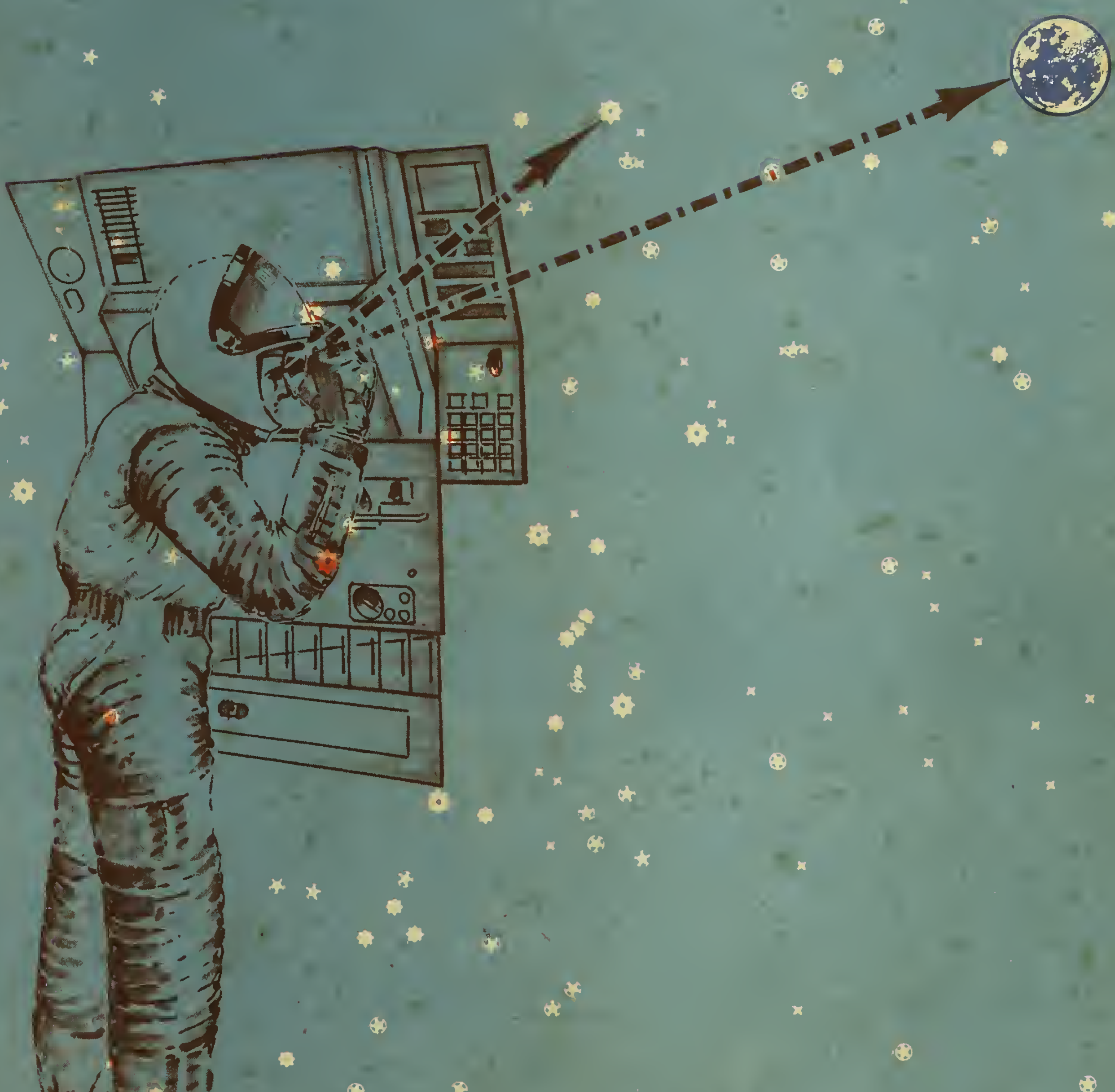
John B. Mortimer
3-17-66

APOLLO GUIDANCE AND NAVIGATION SYSTEM STUDY GUIDE

BLOCK I (SERIES 100) G&N SYSTEM FAMILIARIZATION



16 HOUR COURSE

AC ELECTRONICS DIVISION

GENERAL MOTORS CORPORATION

APOLLO

GUIDANCE & NAVIGATION SYSTEM

BLOCK I (SERIES 100)

STUDENT STUDY GUIDE

GUIDANCE & NAVIGATION SYSTEM

FAMILIARIZATION COURSE 116

PREPARED BY

AC ELECTRONICS

DIVISION OF GENERAL MOTORS

1 JUNE 1965

REVISED: 25 JUNE 1965

REVISION B: 15 FEBRUARY 1966

PREFACE

This student study guide has been prepared by AC Electronics in response to:

Contract Change Order 42 to NAS 9-497

for

System Assembly and Test, Inertial

Measurement Unit, Coupling Display Unit

Power and Servo Assembly - Project APOLLO

This study guide contains training material and should be used for instructional purposes only.

TABLE OF CONTENTS

CONTENTS (cont)

CONTENTS (cont)

LIST OF ILLUSTRATIONS

LIST OF TABLES

OBJECTIVES

The function of this study guide is to familiarize the student with the G & N system and is intended to be used in conjunction with the G & N System Familiarization Course No. 116. The study guide will be presented to the student on the first day of the course and retained by the student after the course as a reference document. Maximum white space is available throughout the study guide to accommodate the student's class notes.

The study guide is organized in the sequence of instruction of the course and is divided into six major sections. Each section contains the documentation and copies of the visual aids used during the class presentation of the section. A summary and review questions are included at the end of each section, to be used by the student for review and self-evaluation. The answers to the review questions are located in the appendix.

The objectives of this study guide are to provide the student with:

a. The course materials organized in the sequence of classroom presentation for self-study.

b. A list of references for further self-study.

c. Section summaries for reviewing.

d. Review questions for self-evaluation.

REFERENCES

The following documents were used in the preparation of this study guide:

ND-1021037	Apollo Guidance and Navigation System Familiarization Manual
ND-1021068	Optical Unit
ND-1021001	Computer Subsystem
ND-1021036	Guidance and Navigation System
ND-1021035	Optics-Inertial Test Set
ND-1021034	Associated Test Equipment
LED-540-12	Design Reference Mission Apollo Mission Planning Task Force
R-477	Guidance and Navigation System Operations Plan
R-467	The Complete Sunrise Being a Description of Program Sunrise
DG Memo No. 330	Navigator's Check List (Preliminary)
1015560	Apollo Inertial Subsystem One Line Mechanization Drawing
1009502	Functional Diagram (Optical Subsystem Block I-100)

SECTION I

INTRODUCTION TO THE G & N SYSTEM

INTRODUCTION

This section develops the G & N requirements for the Apollo mission, describes the relationship of the G & N system to the spacecraft and the astronaut, and briefly discusses the G & N functions as related to the Apollo lunar orbit mission phases.

1.1 GUIDANCE AND NAVIGATION REQUIREMENTS

The Apollo G & N system performs two basic functions: inertial guidance and optical navigation as shown in Figure 1-1. These two basic functions are discussed below.

1.1.1 INERTIAL GUIDANCE. The inertial guidance portion of the G & N system employs accelerometers mounted on a gyroscopically stabilized gimbal-mounted platform and a central data processing element. The inertial guidance system senses acceleration and attitude changes instantaneously and provides attitude control and thrust control signals to the stabilization and control system.

1.1.2 OPTICAL NAVIGATION. The optical navigation portion of the G & N system employs a scanning telescope and sextant to make sightings of celestial bodies and landmarks on the surface of the moon and earth. These sightings are used by the central data processing element to:

a. Determine the spacecraft position and velocity.

b. Establish proper alignment of the stable platform.

A digital computer serves as the central data processing element of the G & N system. It contains a catalog of celestial bodies and is programed to calculate steering, thrust and alignment commands using the information obtained from the optical sightings and the inertial measurement unit. The computer uses data on gravitational fields and celestial perturbations to calculate future position and velocity of the spacecraft.

1.2 G & N SYSTEM INTERFACE

The Apollo G & N system has direct interface with six spacecraft systems: stabilization and control system (SCS), service propulsion system (SPS), reaction control system (RCS), electrical power system (EPS), environmental control system (ECS), and communication and instrumentation system (C&IS). The G & N system interface with the various spacecraft systems is illustrated in figure 1-2 and described in the paragraphs below.

1.2.1 SPACECRAFT SYSTEMS INTERFACE.

1.2.1.1 Stabilization and Control System. The stabilization and control system (SCS) is located in the command module and can sense and control spacecraft attitude and velocity changes during any phase of flight. Steering and thrust signals can be generated either by the stabilization and control system or the G & N system. The signals are processed and conditioned by the stabilization and control system and used to operate the reaction control and service propulsion systems.

The stabilization and control system consists of a rate gyro package, an attitude gyro accelerometer package, electrical control assemblies, attitude gyro coupler unit and various

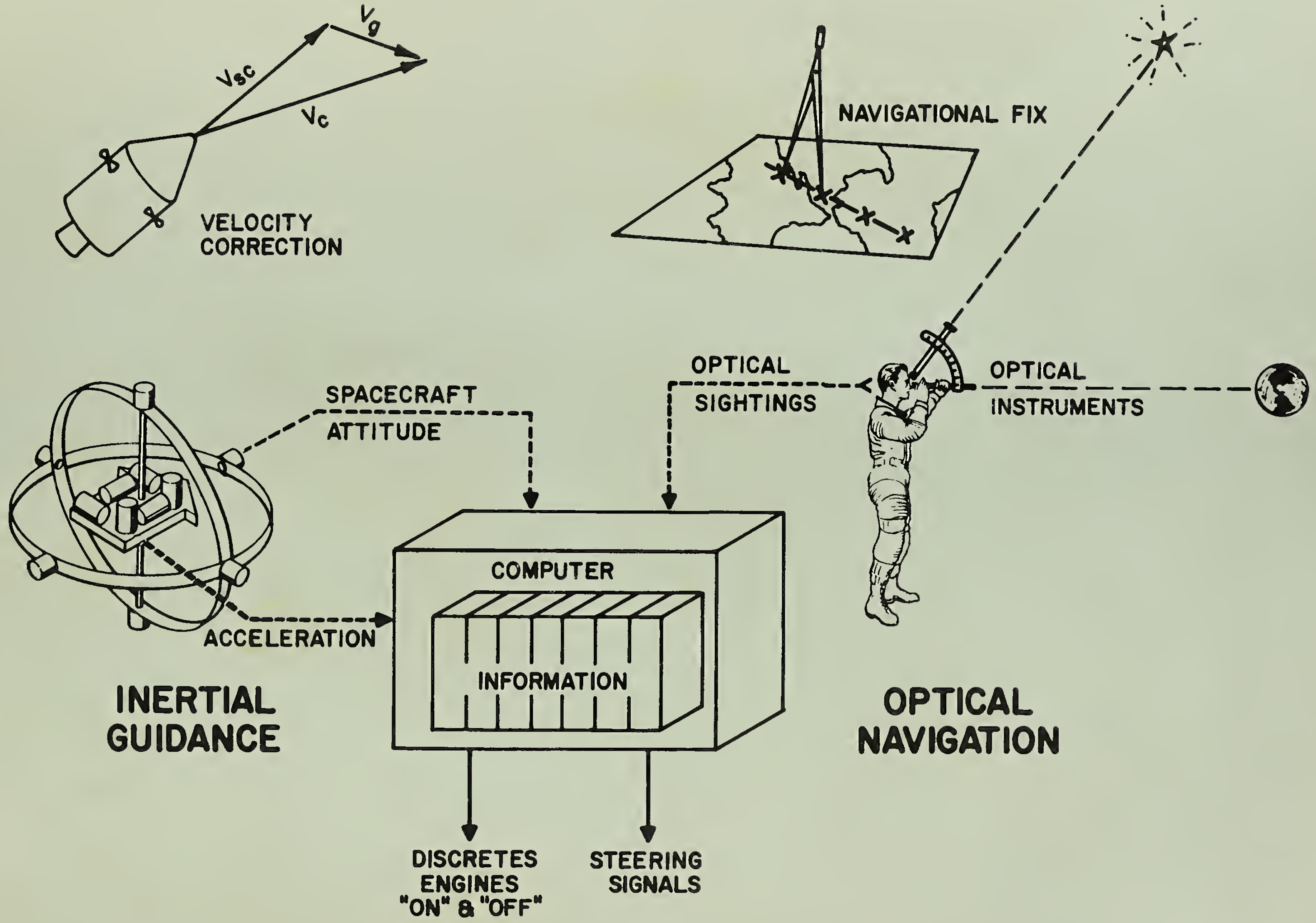


Figure 1-1. Guidance and Navigation Requirements

displays and controls. The stabilization control can hold the spacecraft attitude to a local vertical by using orbital rates or to a specific attitude by using reference gyros mounted to the spacecraft body. Information about attitude and attitude rate of change of the spacecraft is displayed to the flight crew.

Interface signals from the G & N system to the stabilization and control system consist of attitude control signals, thrust commands, mode control and attitude data for display.

1.2.1.2 Service Propulsion System. The service propulsion system (SPS) provides the thrust capability to change the spacecraft's velocity. The system is normally operated by the G & N system through the stabilization control system, but can be operated directly in emergencies.

The service propulsion system is utilized for mission abort, midcourse velocity corrections and orbital injections. The system is located in the service module and consists of helium, fuel and oxidizer storage tanks, a gimbaled thrust chamber, propellent control valves and distribution equipment. The service propulsion system operates on a helium-pressurized hypergolic propellant and is capable of developing 21,900 pounds of thrust. The gimbal mechanism allows the thrust chamber to be displaced $0 \pm 6°$ in pitch and $4 \pm 8°$ in yaw.

1.2.1.3 Reaction Control Systems. Two reaction control systems (RCS) are utilized for attitude control and stabilization of the spacecraft. The systems also can be operated by the G & N system through the stabilization control system. One reaction control system is required for the command module and another for the service module. Each system consists of helium, fuel and oxidizer tanks, propellent control valves, fixed thrust chambers and distribution equipment.

The reaction control system of the command module consists of two independent, and equally capable, pressurized reaction jet subsystems. The two subsystems are operated simultaneously and provide three-axis control of the command module. In event one reaction jet subsystem fails, the remaining reaction jet subsystem is capable of providing the control necessary for safe entry. The reaction jet subsystem provides four engine nozzles for each type of maneuver - roll, pitch and yaw. Each of the 12 engines develops a nominal thrust of 100 pounds and they exhaust through ports flared into the skin of the command module. The engines are located in the aft equipment and forward parachute compartments of the command module.

The service module reaction control system consists of four equally capable hypergolic propellent pressurized reaction jet subsystems. The subsystems are located in the forward section of the service module and are mounted 90° apart. Each subsystem has four engine nozzles. Eight of the 16 nozzles are used for roll control, four for pitch and four for yaw. Each nozzle provides a nominal thrust of 100 pounds.

1.2.1.4 Electrical Power System. The primary power required to operate the G & N system is supplied by a hydrox fuel cell in the service module and is used during all mission phases except entry and recovery. Three zinc-silver oxide storage batteries in the command module furnish power during entry and recovery.

The hydrox fuel cell contains three independent modules, operating in parallel and capable of producing a 27 to 31 volt dc output which is converted by a solid state inverter into 115 volt, 400 cycle power, and together these are used for normal G & N system operation. In case of an emergency, any two modules could meet all power requirements. The modules utilize hydrogen and oxygen as the reactants and potassium hydroxide as the electrolyte. The reactants are stored in tanks that are part of the cryogenic gas storage system which also furnishes oxygen to the environmental control system. The water formed by operating

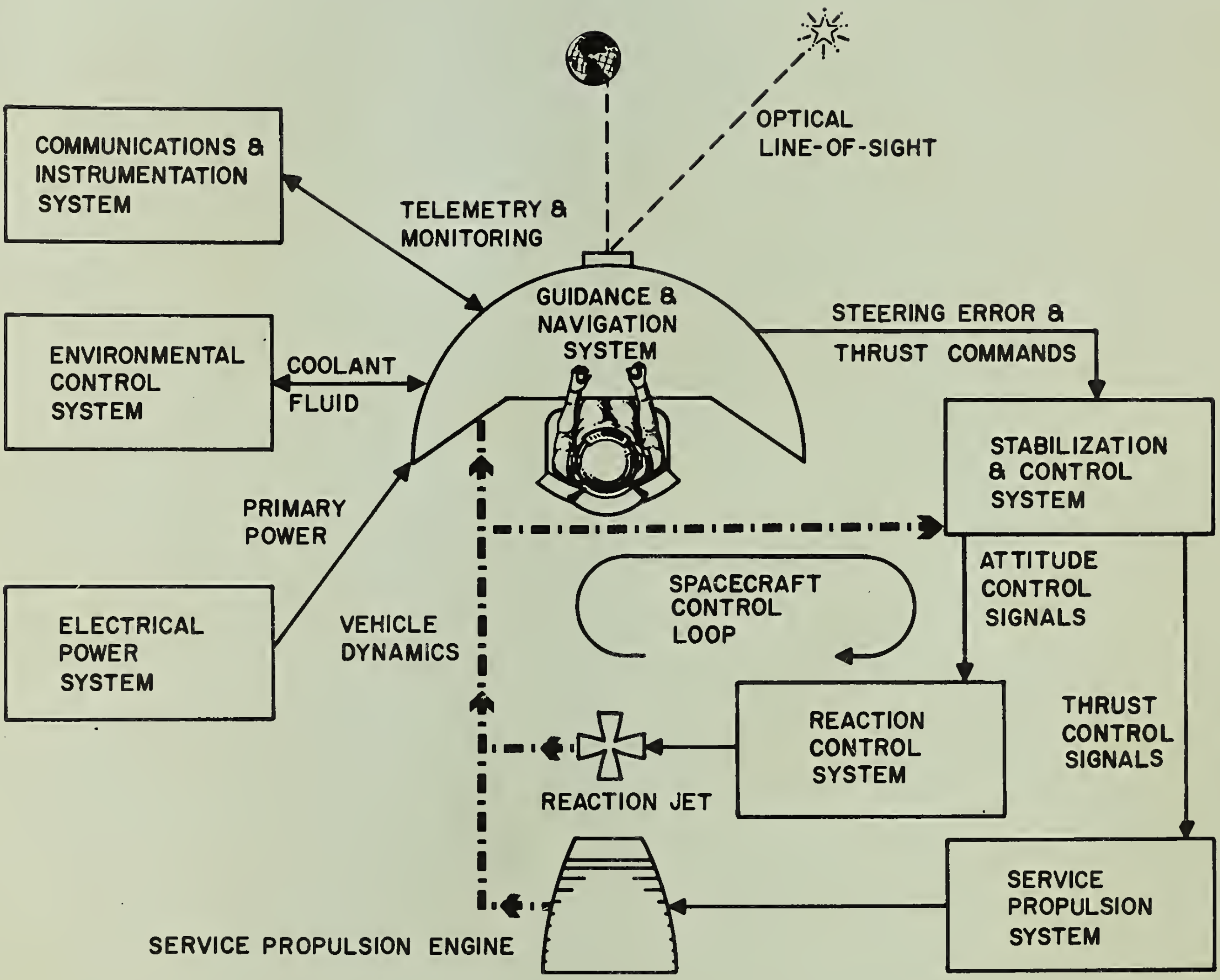


Figure 1-2. Guidance and Navigation System Interface

the fuel cells is collected and delivered to the environmental control system as potable water.

Auxiliary electrical power is provided by the three batteries in the command module. Two of these batteries supply supplementary power during peak loads on the fuel cell. The third battery is isolated from the electrical power system and is used only for post-landing loads. A solid state battery charger is provided to recharge any of the three batteries after normal or emergency discharge.

1.2.1.5 Environmental Control System. An environmental control system (ECS) is used to sustain life in space. The system provides breathable atmosphere, acceptable temperatures, food and water, waste disposal and radiation protection. The Apollo environmental control system is essentially a storage type in which the life support elements (breathable gasses, water, food, etc.) are stored and used as needed, and the waste products collected and stored for disposal. However, some features of a regenerative system in which usable material is extracted from the metabolic waste are used in the Apollo environmental control system, especially in the conservation of water.

The environmental control system provides an atmosphere of 100 percent oxygen at approximately 5 psia. Cabin temperature is maintained between 70 and 80°F. and relative humidity between 50 and 60 percent. In addition, a water-glycol coolant fluid is circulated about the temperature sensitive components of the G & N system and other spacecraft systems for thermal stability. In the event of cabin decompression, the crew pressure suits supply a conditioned oxygen atmosphere of 3.5 psia.

1.2.1.6 Communication and Instrumentation System. The Apollo communication and instrumentation system (C&IS) provides voice, television and telemetry communications with the earth and voice communications between crew members. A television system permits ground viewing of external and remote sections of the spacecraft during flight. Telemetry data can be stored when direct communication with the earth is not possible because of the location of earth communication facilities or because the spacecraft is behind the moon. The earth stations can determine spacecraft position and transmit this information to the crew to supplement information obtained from onboard navigational systems. Critical signals of the G & N system are conditioned and supplied to pulse code modulated (PCM) telemetry equipment for transmission to ground stations. Data transmitted from earth stations can be loaded into the G & N system.

1.2.2 ASTRONAUT INTERFACES. The astronaut is an active and controlling part of the G & N system. He is able to monitor information to and from the G & N system and can manually duplicate G & N system control functions. The astronaut activities are classified into the following five types:

a. Take Optical Sighting: The astronauts identify and select celestial objects on which optical sightings are taken. The sightings are used to align the inertial reference and determine spacecraft position.

b. Monitor System Performance: Mode, condition, and failure lights are monitored by the astronauts to determine system status. As calculations are performed by the computer, the results are displayed for astronaut evaluation and verification with ground calculated data.

c. Load Data: Data is loaded into the computer through the computer keyboard by the astronaut. The data consists of such information as star selection, positional data and system angles.

d. Select Mode of Operation: The astronaut, by means of the displays and controls, can select the equipment modes of operation for the different spacecraft systems required to perform a particular function. In some cases, the sequencing of modes is controlled by the computer. The major mode or program being performed by the computer can be selected by the astronaut or initiated internally by the computer.

e. Provide System Backup: In case of G & N system failure, the astronaut provides manual control of the spacecraft and performs those functions normally performed by the G & N system.

1.3 G & N SUBSYSTEMS

The G & N system is divided into three major subsystems: inertial (ISS), optical (OSS), and computer (CSS). The G & N system is designed so that each subsystem can be operated independently during an emergency or backup mode. Therefore, the failure of one subsystem will not place the entire G & N system out of commission. The three subsystems, or combinations of subsystems, with assistance from the astronaut can perform the following functions:

a. Periodically establish an inertial reference which is used for measurements and computations.

b. Align the inertial reference by precise optical sightings.

c. Calculate the position and velocity of the spacecraft by optical navigation and inertial guidance.

d. Generate attitude error signals and thrust commands necessary to maintain the required spacecraft trajectory.

e. Provide the astronaut with a display of data which indicates the status of the guidance and navigation problem.

1.3.1 G & N SYSTEM EQUIPMENT. The G & N system equipment (figure 1-3 and 1-4) consists of a navigation base (N. B.), inertial measurement unit (IMU), optical assembly, power and servo assembly (PSA), Apollo guidance computer (AGC), display and control panel, and coupling display units (CDU's).

Figure 1-5 shows the G & N system equipment installed in the spacecraft. The navigation base is mounted to the spacecraft sidewall and used as a holding fixture for the IMU and optical assembly. The IMU and optical assembly are attached and precisely aligned to the navigation base. The display and control panel comprises the front of the G & N structure and contains several individual panels. These panels are located so that the astronaut can view and manually operate them from a standing position. The CDU's are also mounted in the display and control panel. The PSA, which contains power supplies, amplifiers and miscellaneous electronics, is located on a shelf below the navigation base. The PSA consists of ten trays which plug into a PSA junction box. The AGC is located on a shelf below the PSA and consists of one tray which plugs into an AGC junction box.

The following paragraphs present a brief functional description of the three G & N subsystems. Figure 1-6 illustrates the signal flow and interface between the subsystems.

1.3.2 INERTIAL SUBSYSTEM. The inertial subsystem consists of the IMU mounted on the navigation base, three CDU's, portions of the PSA, and portions of the lower display and control panel.

The inertial subsystem is used in spacecraft guidance to determine the direction and magnitude of the required velocity correction applied to the spacecraft. To conserve fuel, velocity corrections are kept to a minimum and are applied only periodically. Therefore, electrical power also can be conserved by limiting the use of the inertial subsystem to about 20 percent

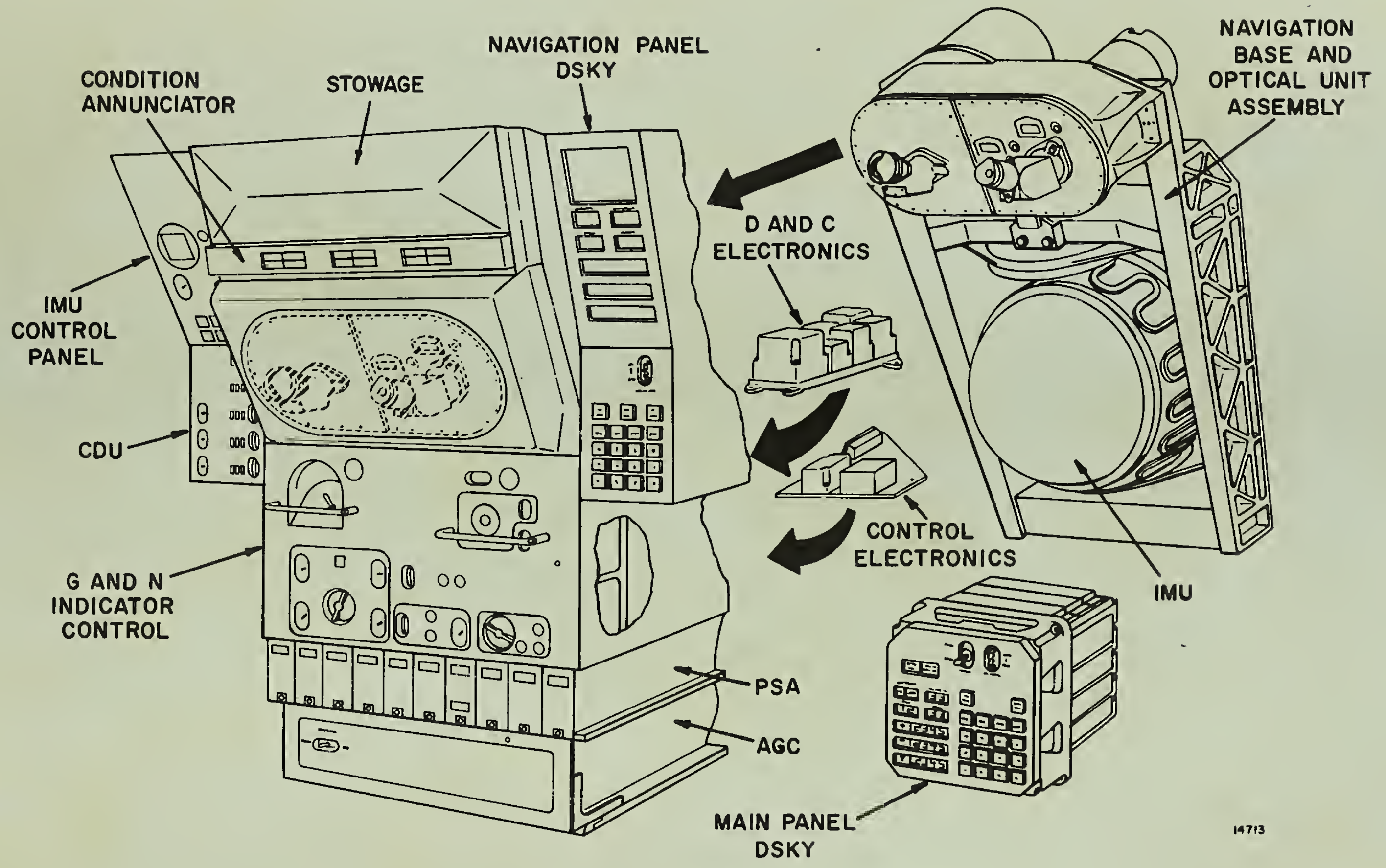


Figure 1-3. Guidance and Navigation Equipment

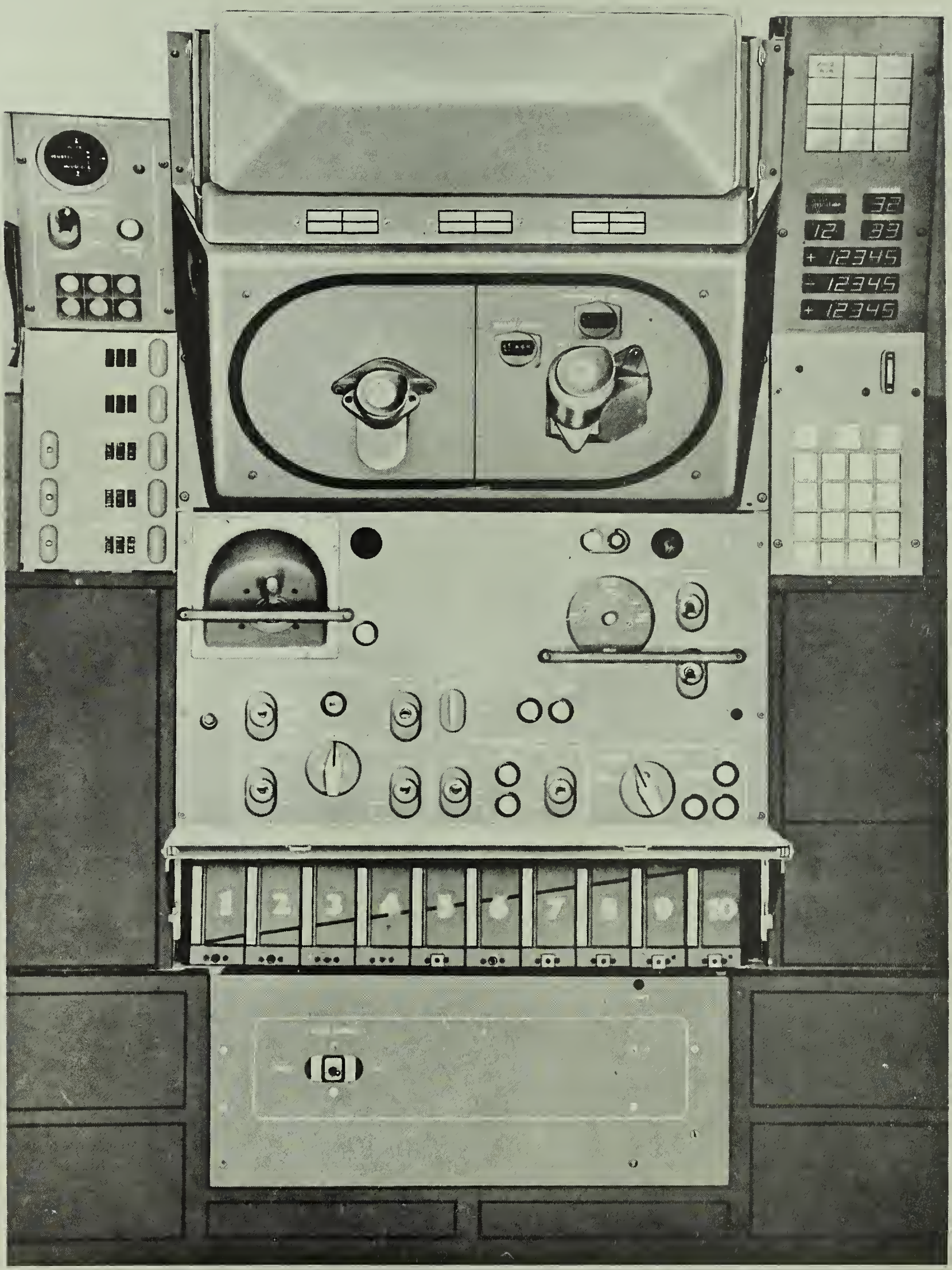


Figure 1-4. Lower Equipment Bay

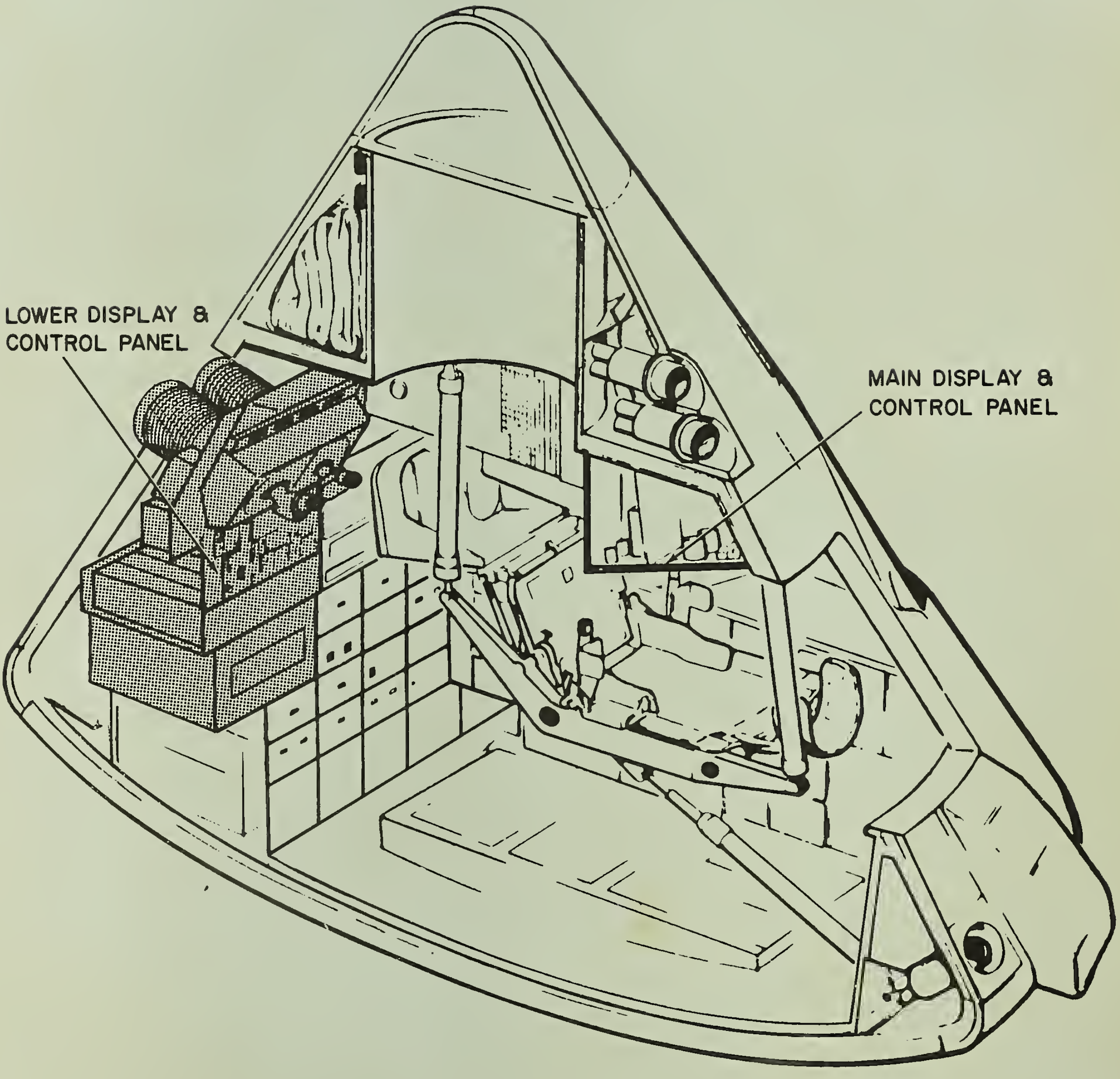


Figure 1-5. Location of Guidance and Navigation Equipment in the Spacecraft

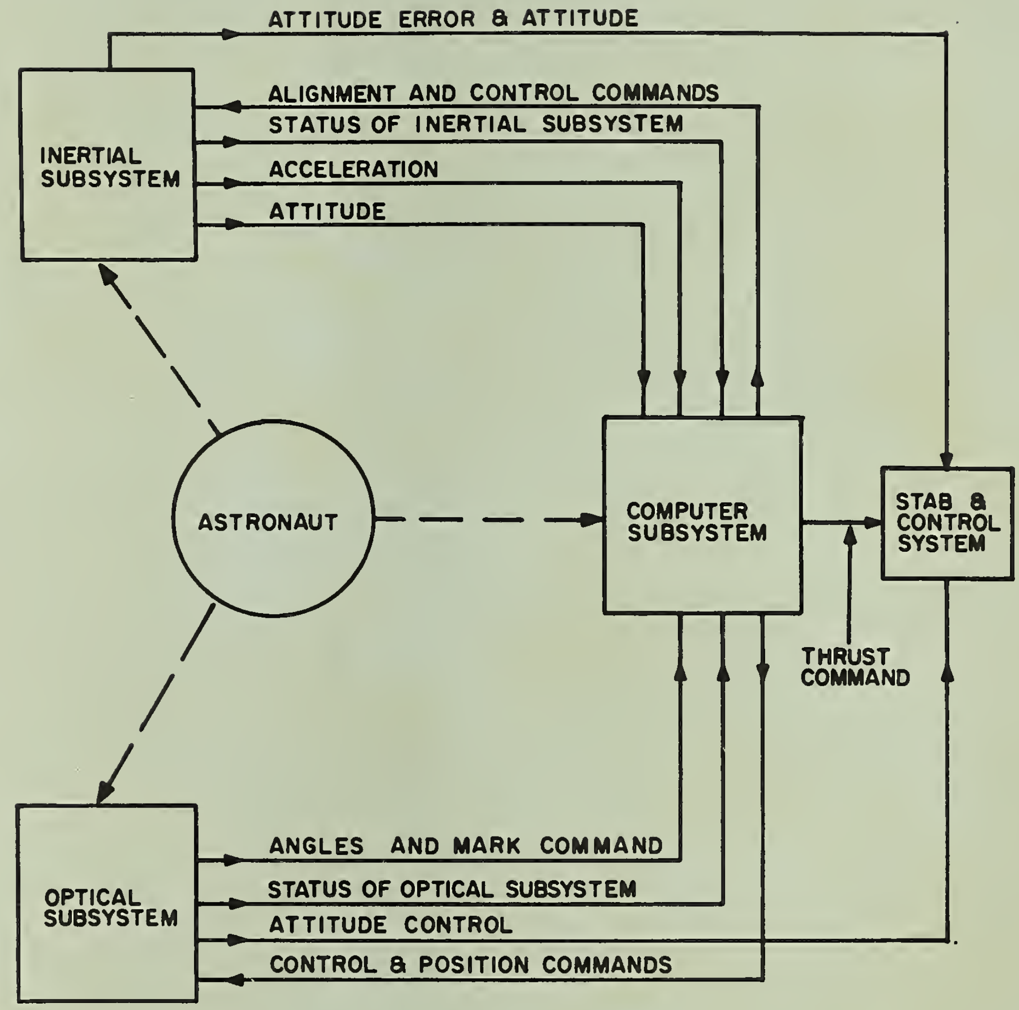


Figure 1-6. Guidance and Navigation Subsystem Data Flow

of the flight time.

The inertial subsystem performs three major functions: (1) measures changes in spacecraft attitude, (2) assists in generating steering commands and (3) measures spacecraft velocity changes due to thrust. To accomplish these functions, the IMU provides an inertial reference consisting of a stable member gimbaled in three degrees of freedom and stabilized by three integrating gyros. Each time the inertial subsystem is energized, the stable member must be aligned with respect to a predetermined reference. When the inertial subsystem is operated prior to launch, the stable member is aligned through a gyro compassing routine and, during flight, it is aligned by sighting the optical instruments on celestial objects. If the inertial subsystem is operated over a prolonged period of time, realignment may be necessary since the gyros which maintain the space referenced stable member may drift and cause an error in flight calculations.

Once the inertial subsystem is energized and aligned, any rotational motion of the spacecraft will be about the gimbaled stable member, which remains rotationally fixed in space. Resolvers, mounted on the gimbal axes, act as angular sensing devices and measure the attitude of the spacecraft with respect to the stable member. These angular measurements are displayed to the astronauts by the CDU's and angular changes are sent to the AGC.

The required gimbal angles to change the spacecraft attitude are calculated in the AGC and compared with the actual gimbal angles. Any difference between the actual and calculated angles causes an attitude error signal to be generated in the inertial subsystem. The error signal is sent to the stabilization control system to correct the spacecraft attitude.

Acceleration of the spacecraft is sensed by three pendulous accelerometers mounted on the stable member with their input axes orthogonal. The resultant signals from the accelerometers are supplied to the AGC which then calculates the total velocity.

The modes of operation of the inertial subsystem can be initiated manually by the astronaut, automatically by the AGC or by astronaut selection of computer program through the computer keyboard. The status or mode of operation is displayed on the display and control panels and supplied to the computer.

1.3.3 OPTICAL SUBSYSTEM. The optical subsystem consists of the optical assembly mounted on the navigation base, two CDU's and portions of the PSA and display and control panel.

The optical subsystem is used to determine the position and orientation of the spacecraft in space. This is accomplished through the use of a catalog of stars stored in the AGC and celestial measurements taken by the navigator. The identity of celestial objects and the schedule of measurements is determined before launch and is based on an optimum plan.

The optical subsystem performs two major functions: (1) provides the AGC with data obtained by measuring angles between lines of sight to celestial objects, and (2) provides measurements for establishing the inertial reference.

The optical subsystem contains a sextant and telescope. The sextant is a high magnification and dual line-of-sight device used for precision angular measurements. The telescope has a wide field of view, one line-of-sight and is used for coarse acquisition of stars and landmarks and orbital tracking of landmarks.

The optical instruments are located side by side on the navigation base. The astronaut makes observations by sighting through one of two eyepieces located on the display and control panel. The modes of operation of the optical subsystem are indicated on the display and control panel and are supplied to the AGC. A manual control stick on the front of the display and control panel is used by the astronaut to position the optical lines-of-sight. Since the optical instrument's field of view is limited, controls are also provided by which the astronaut can maneuver the entire spacecraft to point the optical instrument in any desired direction. The astronaut initiates a timing mark which causes the AGC to record both optical angles and the time at the instant the sextant is properly pointed for a measurement.

1.3.4 COMPUTER SUBSYSTEM. The computer subsystem consists of the Apollo guidance computer and portions of the display and control panels.

The computer subsystem is used to perform space flight data handling and computations. The AGC is a general purpose digital computer employing a core memory, parallel operations and a built-in self-check capability.

Programs are stored in the AGC and selected to control and solve flight equations. The selection of programs can be controlled by automatic sequencing or manually by the astronaut.

The computer subsystem performs five major functions: (1) calculates steering signals and engine discretes necessary to keep the spacecraft on the required trajectory, (2) positions the stable member in the IMU to a coordinate system defined by precise optical measurements, (3) positions the optical unit to celestial objects, (4) conducts limited malfunction isolation of the G & N system by monitoring the level and rate of system signals and (5) supplies pertinent spacecraft condition information to the display and control panel.

Using information from navigation fixes, the AGC computes deviations from the required trajectory and calculates the necessary corrective attitude and thrust commands. The velocity corrections are controlled by the computer subsystem by processing incremental velocity from the inertial subsystem. Velocity corrections are not made continuously, but rather are initiated at predetermined check points in the flight. The technique of check point velocity corrections reduces fuel consumption, since the engines are used only when a significant correction in velocity is required. The AGC also uses information from celestial measurements to align the stable member in the IMU to a defined coordinate system.

Malfunctions in the G & N system are detected by the AGC by monitoring critical signals and rates. Lamps on the display and control panel light to indicate malfunctions.

Lamps on the display and control panel indicate the program being solved by the AGC or the results of calculations. Selection of a computer program or insertion of data into the AGC can be done by the astronaut with a keyboard on the display and control panel or by uplink data through the communication and instrumentation system from the ground station.

1.4 G & N SYSTEM FUNCTIONS AND RELATION TO MISSION PHASES

There are nine major G & N system functions associated with the Apollo lunar orbit mission phases: (1) prelaunch IMU alignment, (2) guidance monitor, (3) orbital navigation, (4) inflight IMU alignment, (5) injection, (6) midcourse navigation, (7) midcourse correction, (8) entry and (9) attitude control. These nine functions are used during the ten mission phases described in Figure 1-7. Table 1-1 tabulates the G & N system functions during each mission phase. The following is a brief description of each function, with additional information provided in Section V of this study guide.

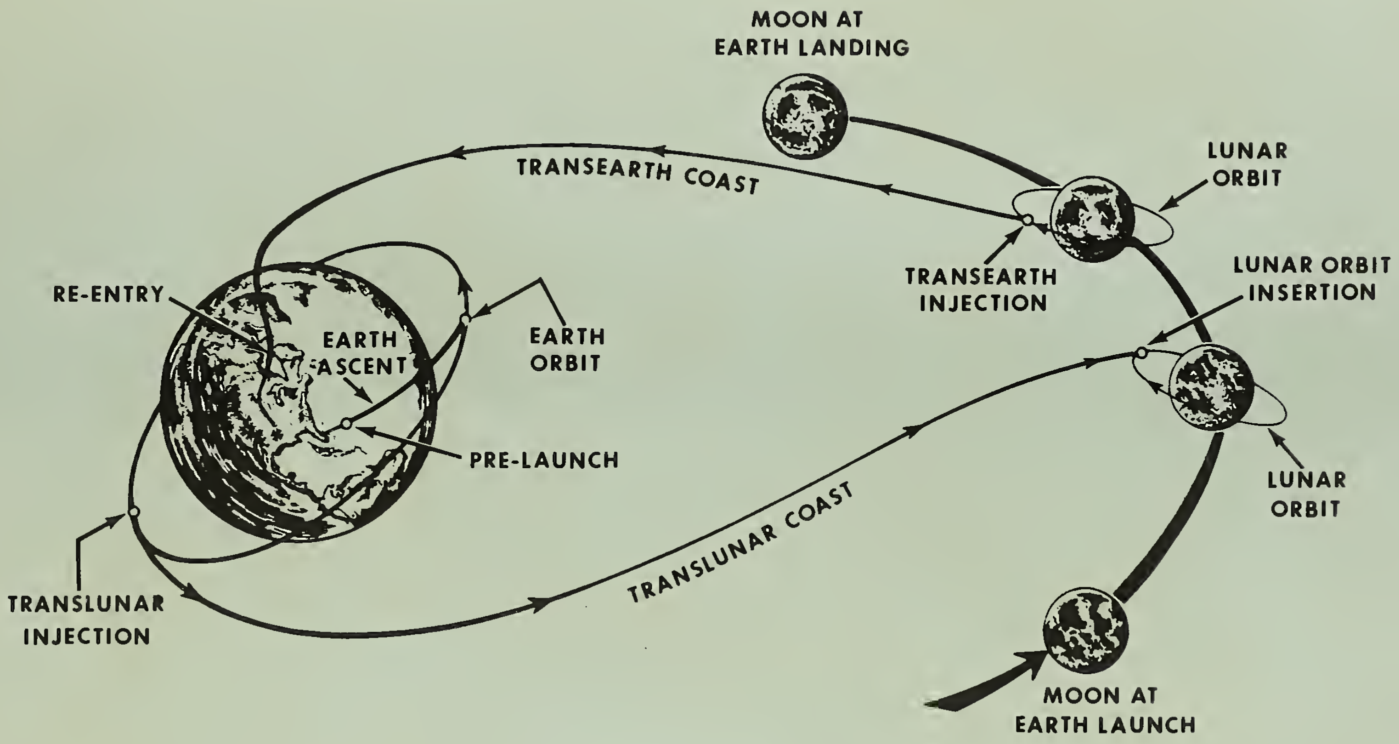


Figure 1-7. Mission Phases Required for a Lunar Orbit

1.4.1 PRELAUNCH IMU ALIGNMENT. During prelaunch alignment, the IMU stable member is vertically erected and aligned in azimuth. The stable member is then held to this earth reference through a gyro compassing routine in the computer. Initial azimuth is determined by sighting on a ground target with the optics prior to closeout of the command module.

1.4.2 GUIDANCE MONITOR. The G & N system monitors the SIV-B guidance during earth ascent and translunar injection. At launch, the IMU is switched from an earth reference (gyro compassing) to a space reference frame (inertially stabilized). The astronaut then uses the G & N system to monitor the spacecraft flight profile.

1.4.3 ORBITAL NAVIGATION. During earth and lunar orbit, the astronaut checks the orbital trajectory and the alignment of the IMU by means of optical sightings. The astronaut takes sightings by identifying and tracking landmarks with the optical instrument. The computer records optical and IMU gimbal angles and calculates the orbital trajectory.

1.4.4 INFLIGHT IMU ALIGNMENT. IMU alignment will be performed during the following mission phases: (1) earth orbit, (2) translunar coast, (3) lunar orbit and (4) transearth coast. IMU alignment in flight is accomplished by means of optical sightings. The astronaut takes star sightings and the computer records the optical and IMU gimbal angles. The computer then calculates and applies torquing commands necessary to align the IMU.

1.4.5 INJECTION. This function is performed at lunar orbit insertion and transearth injection. The G & N system places the spacecraft into the proper orientation (spacecraft X axis along the calculated thrust vector) and controls and monitors the thrusting of the spacecraft.

NOTE: The SIV-B guidance system is primary control for translunar injection.

1.4.6 MIDCOURSE NAVIGATION. This G & N function is performed many times during the translunar and transearth mission phases. Midcourse navigation is accomplished by taking star-landmark optical sightings. The computer records the optical angles and the time of sighting. Spacecraft position and velocity can then be updated by the computer.

1.4.7 MIDCOURSE CORRECTION. Approximately three midcourse corrections are performed during the translunar and transearth coast phases of the mission. The computer, after calculating the spacecraft position and velocity from a midcourse navigation sighting, determines the need for a midcourse correction. This is done by comparing the actual trajectory to the required trajectory. If a midcourse correction is necessary, the computer calculates the thrust vector and the velocity change needed, repositions the spacecraft and controls the thrusting of the SPS.

1.4.8 ENTRY. This G & N function is performed during entry into the atmosphere. The G & N system controls the flight path of the command module. The computer determines the proper trajectory and steers the command module along this trajectory. Steering is accomplished by rolling the command module about the navigation base X axis. This changes the lift to drag ratio of the command module, and thereby varies the trajectory.

1.4.9 ATTITUDE CONTROL. This G & N function is used during the translunar and transearth coast phases when the ISS is activated. The ISS then provides the inertial reference to maintain the spacecraft attitude.

1.5 SUMMARY

The G & N system performs two basic functions: optical navigation and inertial guidance. Optical navigation is accomplished by using a scanning telescope and a sextant. The scanning telescope is used to acquire the celestial object and the sextant is used to accurately measure the angles to these objects. The angles are inserted into a computer which performs the calculations necessary for space navigation.

LUNAR ORBIT MISSION PHASES	PRELAUNCH IMU ALIGNMENT	GUIDANCE MONITOR	ORBITAL DETERMINATION	INFLIGHT IMU ALIGNMENT	INJECTION	MIDCOURSE NAVIGATION	MIDCOURSE CORRECTION	ENTRY	ATTITUDE CONTROL
PRELAUNCH	X								
EARTH ASCENT		X							
EARTH ORBIT			X	X					
TRANSLUNAR INJECTION		X							
TRANSLUNAR COAST				X		X	X		X
LUNAR ORBIT INSERTION					X				
LUNAR ORBIT			X	X					
TRANSEARTH INJECTION					X				
TRANSEARTH COAST				X		X	X		X
ENTRY								X	

Table 1-1. G & N System Functions per Mission Phase

Inertial guidance is accomplished by the use of an inertially stabilized platform. Three stabilization gyros mounted on the platform and a three degree of freedom gimbaling system provide the inertial stabilization. Three accelerometers, also mounted on the platform, provide the computer with changes in velocity. These changes in velocity are accumulated in the computer. The computer, using these velocity changes, time and certain constants, then calculates the spacecraft position in space. The stable platform of the inertial measurement unit is also used for an inertial reference in space. From this reference, spacecraft attitude can be controlled.

The G & N system interfaces with the astronaut and six basic spacecraft systems: the Electrical Power System (EPS), the Environmental Control System (ECS), the Communications and Instrumentation System (C&IS), the Stabilization Control System (SCS), the Reaction Control System (RCS) and the Service Propulsion System (SPS). The G & N system receives prime power from the EPS, cooling from the ECS and ground information from the C&IS. The G & N system provides steering and thrusting commands to the SCS which, in turn, routes these commands to the RCS for attitude control and to the SPS for thrust and steering control. The G & N system also provides system information to the C&IS for transmission to the ground stations.

The astronaut:

a. Loads data into the computer.

b. Monitors the systems operation.

c. Can control the mode selection of the system.

d. Provides system backup.

e. Takes optical sightings.

The G & N system consists of seven major components. These components are listed below:

a. Navigation Base (NB)

b. Inertial Measurement Unit (IMU)

c. Optical Unit

d. Coupling Display Units (CDU's)

e. Power and Servo Assembly (PSA)

f. Display and Control Panels

g. Apollo Guidance Computer (AGC)

The G & N system equipment is divided into three subsystems: inertial subsystem (ISS), optical subsystem (OSS) and computer subsystem (CSS).

The G & N system is required to perform nine functions during a lunar orbit mission. These functions and their relationship with the Apollo mission phases for a lunar orbit mission are listed below:

a. Prelaunch IMU alignment - performed prior to final countdown.

b. Guidance monitor - performed during launch and translunar injection.

c. Orbital determination - performed during earth and lunar orbit.

d. Inflight IMU alignment - performed during earth orbit, translunar coast, lunar orbit and transearth coast.

e. Injection - performed during lunar orbit injection and transearth injection.

f. Midcourse navigation - performed during translunar and transearth coast.

g. Midcourse correction - performed during translunar and transearth coast.

h. Entry - performed during earth entry.

i. Attitude control - performed during translunar and transearth coast when the ISS is activated.

REVIEW QUESTIONS FOR SECTION I

1. The G & N system performs two basic functions: optical navigation and inertial guidance. Briefly explain how these functions are accomplished.

   a.

   b.

2. The G & N system interfaces with six major spacecraft systems: EPS, ECS, SCS, RCS, SPS and C&IS. Briefly explain the purpose of each system as related to the G & N system.

   a. EPS

   b. ECS

   c. SCS

   d. RCS

   e. SPS

   f. C&IS

3. The G & N system consists of seven major components. List these components.

a.

b.

c.

d.

e.

f.

g.

4. The G & N system is divided into three subsystems. List the subsystems.

a.

b.

c.

SECTION II

INERTIAL SUBSYSTEM

INTRODUCTION

This section describes the inertial subsystem hardware, classifies the inertial subsystem into functional blocks, discusses the functional blocks and describes the inertial subsystem modes.

2.1 ISS PURPOSE

The inertial subsystem of the G & N system maintains an inertial reference and senses instantaneously any thrust applied to the spacecraft. The capacity to sense acceleration is used during major thrusting maneuvers. The functions of the inertial subsystem -- attitude control and acceleration measurement -- are performed primarily when thrust is applied to the spacecraft. The inertial subsystem is turned on and off as required during the flight. The optical subsystem is used to take sightings on celestial objects; these sightings are used in calculating spacecraft position and velocity and in aligning the inertial measurement unit (IMU) during flight.

In preparation for the Apollo mission, the optimum guidance equations are selected and the required constants are stored in the Apollo guidance computer (AGC), thus dependence on a reference trajectory is kept to a minimum.

The inertial subsystem measures acceleration along the axes of the IMU stable member coordinate system and supplies incremental velocity data to the AGC. To determine spacecraft position and velocity, the components of velocity due to gravitational field accelerations are added to the velocity acquired as a result of thrusting (acceleration measured by the accelerometer loops). Using the resultant total velocity and the last known position and velocity, the AGC calculates the present position and velocity of the spacecraft. The position and velocity data are used during spacecraft velocity correction to determine when the proper trajectory has been obtained and when thrusting can be stopped.

The inertial subsystem can be used to control spacecraft attitude. The attitude of the spacecraft, with respect to the stable member, is determined by means of resolvers which measure the gimbal angles. The difference between the actual orientation of the spacecraft with respect to the IMU stable member and the orientation commanded by the navigator or the AGC results in an attitude error signal which can be applied to the stabilization and control system (SCS).

Alignment of the stable member in flight is necessary because of gyro drift and on-off cycling of the inertial subsystem. Two star sightings are needed for coarse alignment of the IMU and two sightings for fine alignment. For coarse and fine IMU alignment, the optical instruments are sighted alternately at two stars. The AGC records the optical angles and time (when MARK COMMAND is issued) and calculates the signals required to align the IMU stable member.

2.2 ISS EQUIPMENT

The inertial subsystem consists of the following equipment (Figure 2-1):

a. Navigation Base (NB)

b. Inertial Measurement Unit (IMU)

c. Coupling Display Unit (CDU) (three required)

d. Power and Servo Assembly (PSA) (portions)

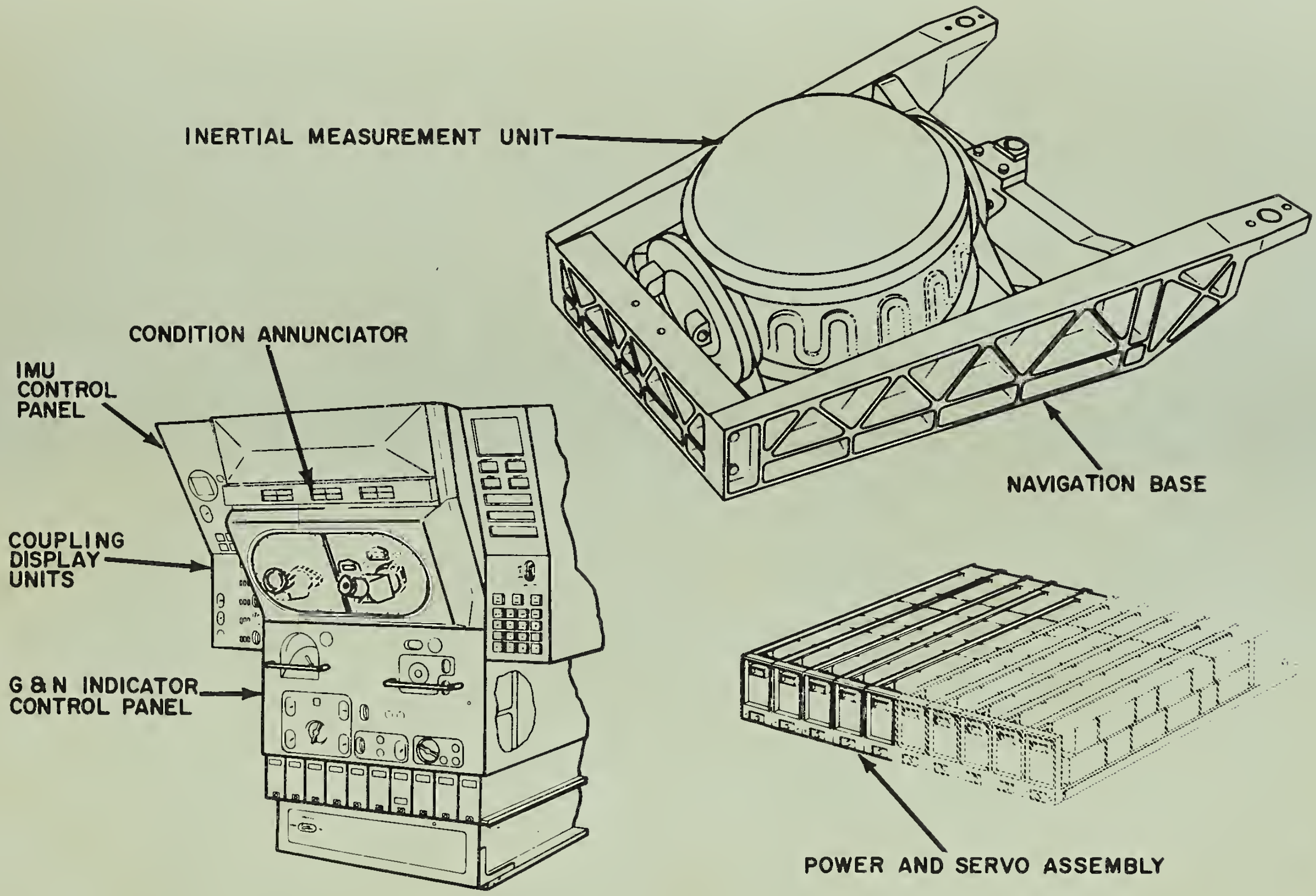


Figure 2-1. Inertial Subsystem Equipment

e. Display and Control Electronics

f. IMU Control Panel

g. G & N Indicator Control Panel

2.3 AXES

Several sets of axes are associated with the ISS. Each set of axes is a right hand orthogonal coordinate system with positive rotation defined by the advancing right hand screw theory. Figure 2-2 shows the relationships of the various sets of axes when the IMU gimbal angles are zero. The following paragraphs define the sets of axes.

2.3.1 SPACECRAFT AXES. The spacecraft axes are designated X_{sc}, Y_{sc} and Z_{sc} and are referred to as roll, pitch and yaw, respectively. They are fixed to the spacecraft center of gravity. The X_{sc} axis is parallel to the spacecraft longitudinal axis and the positive end is toward the apex of the command module. The Y_{sc} and Z_{sc} axes are perpendicular to the X_{sc} axis and to each other.

2.3.2 NAVIGATION BASE AXES. The navigation base is mounted to the command module wall which is slanted at an angle of 33° with respect to the spacecraft X axis. The navigation base axes are designated X_{nb}, Y_{nb} and Z_{nb}. The X_{nb} axis is displaced 33° from the X_{sc} axis in the X_{sc} Z_{sc} plane, making the X_{nb} axis parallel to the spacecraft wall. The Y_{nb} axis is parallel to the Y_{sc} axis. The Z_{nb} axis is displaced upward 33° from the Z_{sc} axis in the $X_{sc}Z_{sc}$ plane.

2.3.3 IMU AXES. The IMU has a set of gimbal axes associated with it, defined by the three IMU gimbal axes (outer, inner and middle). These axes are designated outer gimbal axis (OGA), inner gimbal axis (IGA) and middle gimbal axis (MGA). The IMU gimbal axes are defined while the gimbal angles are zero as follows: the OGA is parallel to the X_{nb} axis, the IGA is parallel to the Y_{nb} axis and the MGA is parallel to the Z_{nb} axis.

The IMU stable member or platform axes are designed X_{sm}, Y_{sm} and Z_{sm} and are parallel to the gimbal axes when the gimbal angles are at zero.

Each of the three stabilization gyros on the stable member have input axes associated with them and they are designated X_g, Y_g and Z_g. These axes are fixed parallel to the stable member X_{sm}, Y_{sm} and Z_{sm} axes, respectively.

The three accelerometers mounted on the stable member also have input axes associated with them. They are designated X_a, Y_a and Z_a. These axes also are fixed parallel to the stable member X_{sm}, Y_{sm} and Z_{sm} axes.

The stable member axes are resolved into navigation base and spacecraft axes so that measurements made from the stable member can be related back to spacecraft and navigation base.

2.4 ISS FUNCTIONAL BLOCKS

For the purpose of explanation, the inertial subsystem equipment is divided into 15 functional blocks as shown in Figure 2-3. The operation and interrelationship of these blocks is described in the following paragraphs.

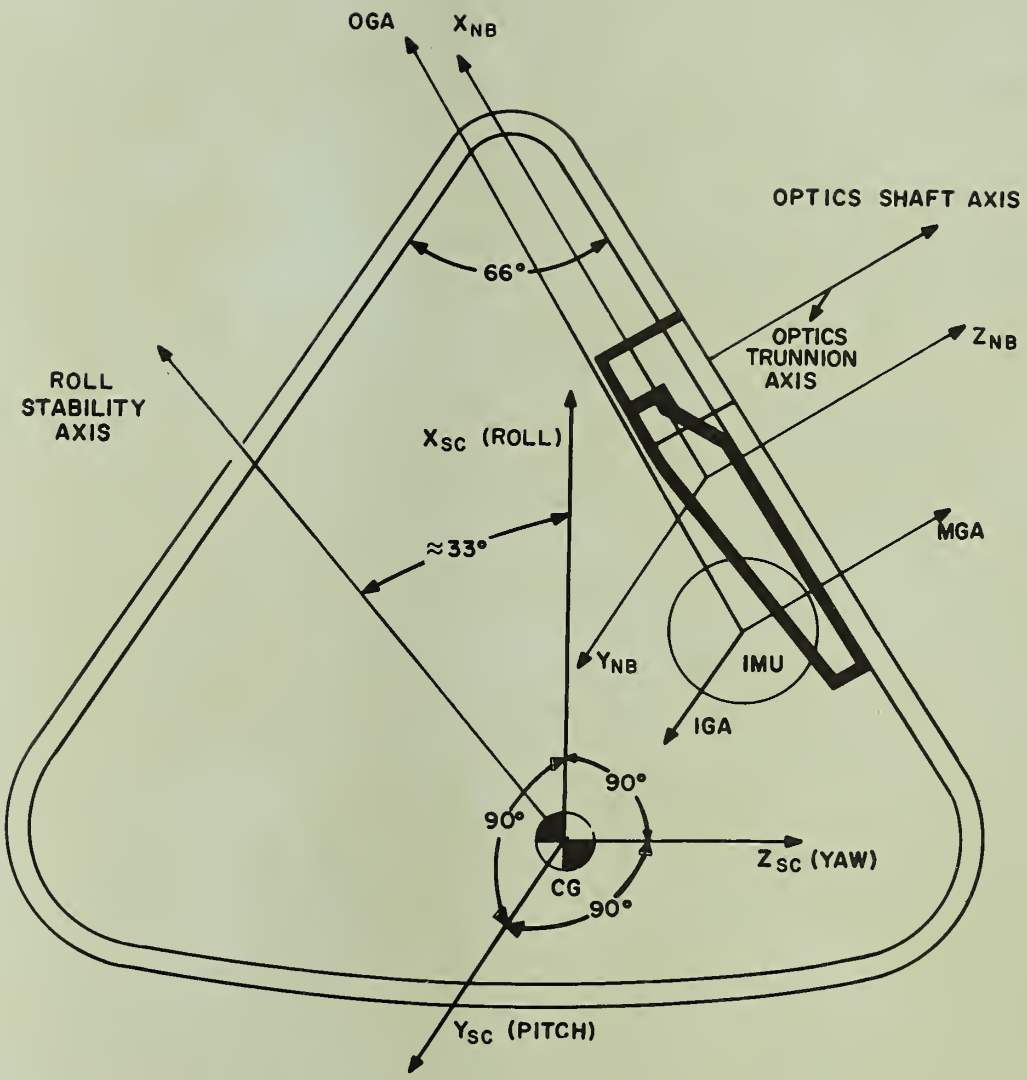


Figure 2-2. Spacecraft and Guidance System Axes

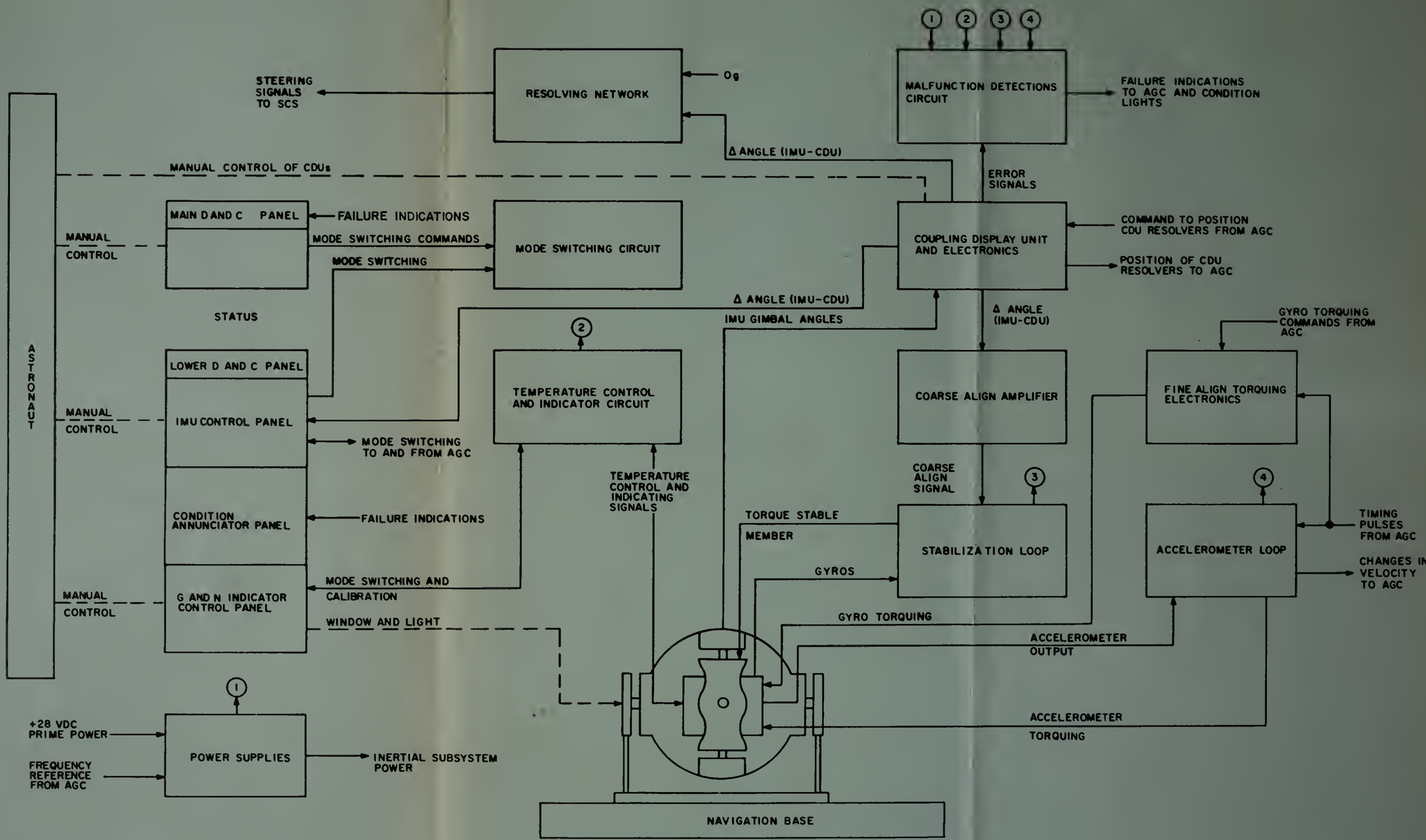


Figure 2-3. Inertial Subsystem Interface

2.4.1 NAVIGATION BASE. The navigation base provides a rigid support for the IMU and optical assembly in the spacecraft. The IMU and optical assembly are precisely aligned on the navigation base.

2.4.2 INERTIAL MEASUREMENT UNIT STRUCTURE. The IMU structure (Figure 2-4) consists of the stable member, gimbaled for three degrees of freedom, with respect to the navigation base. The three gimbals (Figure 2-5) allow the stable member to remain nonrotating in space.

The orientation of the stable member, with respect to the navigation base, is measured by resolvers on the gimbal shafts. The resolver gimbal angle output signals are supplied to the CDU's by mode switching. The CDU's can repeat the IMU gimbal angles, which can then be supplied to the AGC by encoders in the CDU's.

Nine inertial components are located in the IMU: three (3) 25 inertial reference integrating gyros (25 IRIG's) and three (3) angular differentiating accelerometers (ADA's) are used in the stabilization loop to sense changes in the orientation of the stable member; and three (3) 16 pulse-integrating pendulums (16 PIP's) are used in the accelerometer loops to sense changes in velocity of the spacecraft.

The temperature of these inertial components is critical and is controlled by the temperature control circuit. The middle and outer gimbals and gimbal case are spherical in shape. The gimbal case contains integral coolant passages and provides hermetic sealing of the unit. A spotlight and windows in the G & N indicator control panel are used for inspection of the IMU for possible coolant leaks.

2.4.3 TEMPERATURE CONTROL AND INDICATOR CIRCUITS. The temperature of the inertial components is held within specified limits by heating elements and temperature control sensors. The circuit has four modes of operation: proportional, autooverride, emergency and backup. The switching between modes and the testing of the circuit calibration is accomplished by controls located on the G & N indicator control panel. To assist in temperature regulation, two blowers, located between the outer gimbal and gimbal case, circulate air through the outer gimbal to pass heat from the middle gimbal to the cooled outer gimbal case. In case of a failure in the temperature control circuit, the temperature no-go lamps on the lower display and control panel light.

2.4.4 STABILIZATION LOOP. The stabilization loop holds the stable member inertial space referenced to a given coordinate system by isolating the stable member from roll, pitch and yaw motions of the spacecraft. The stable member serves two purposes in the system: (1) acts as a reference for measuring the attitude of the spacecraft and (2) holds the three accelerometers (used in space for measuring acceleration due to thrust) in a fixed coordinate system.

When the stabilization loop holds the stable member inertial referenced, the 25 IRIG's on the stable member and ADA's on the stable member and middle gimbal generate error signals to indicate any change in the orientation of the stable member with respect to inertial space. The error signals are amplified by the servo amplifiers in the PSA and are supplied to the IMU gimbal torque motors, which reposition the stable member.

When the stabilization loop is energized, the stable member is spaced referenced to the spacecraft by the coarse align loops. The stable member must then be aligned to the desired orientation. The alignment is done in two steps, coarse align and fine align. The coarse align is done first and is accomplished by injecting coarse align signals into the stabilization loop servo amplifiers. The fine align is accomplished by injecting a fine align signal from the AGC into the torque ducosyn of each of the 25 IRIG's. During prelaunch, the stable member is held earth-referenced by supplying the 25 IRIG's with the appropriate torquing signals.

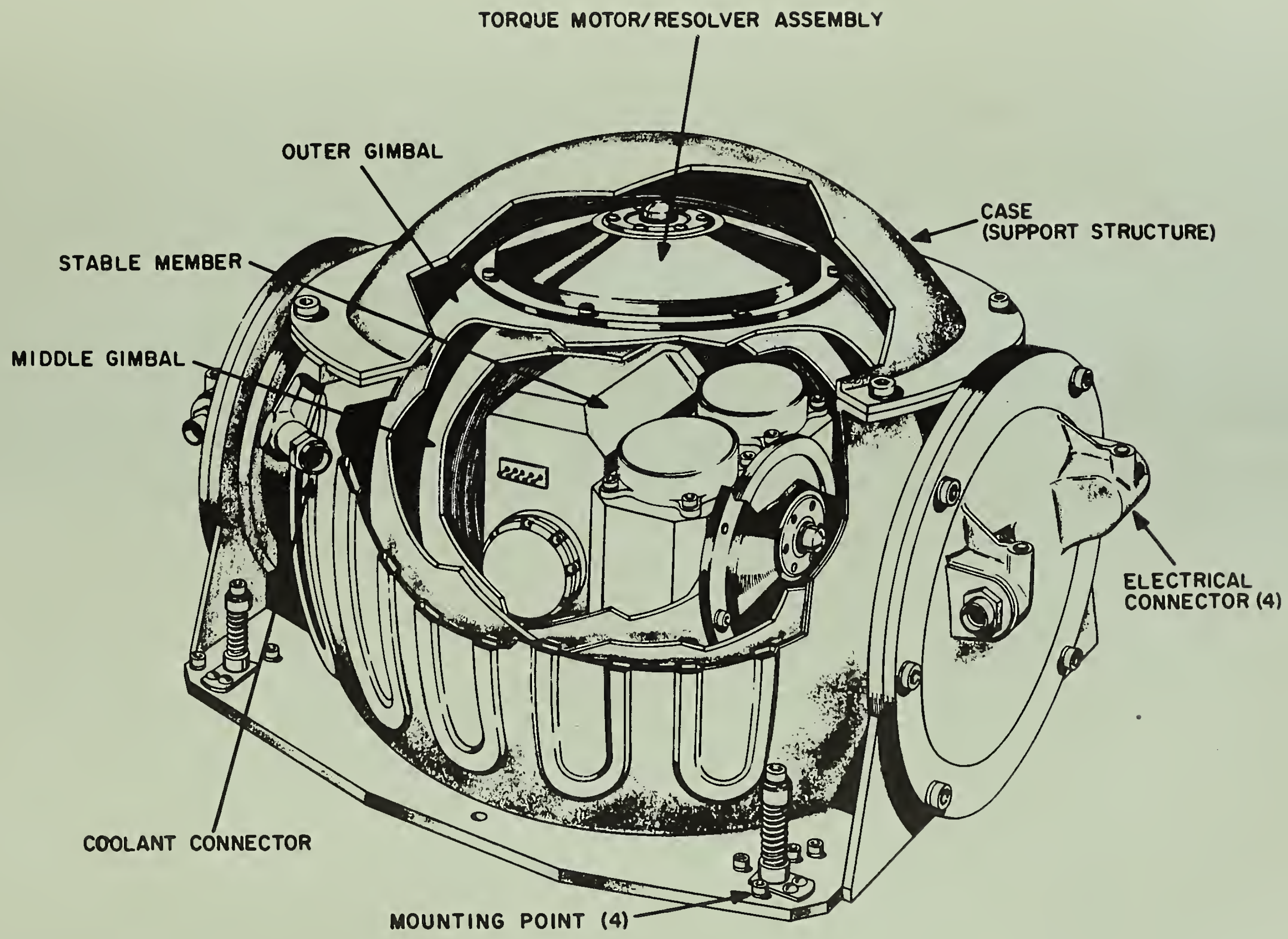


Figure 2-4. Inertial Measurement Unit

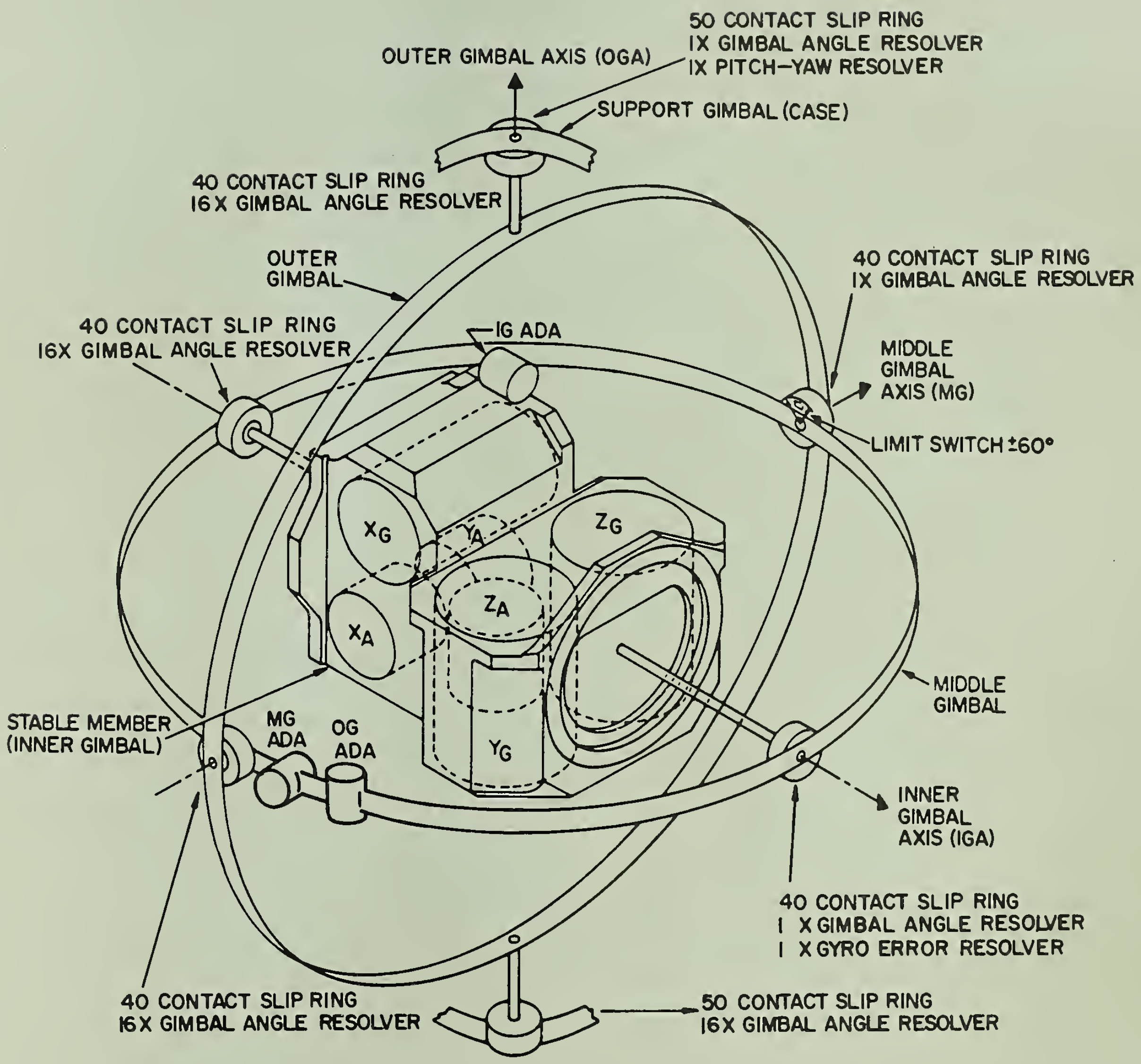


Figure 2-5. IMU Gimbal Assembly

2.4.5 COARSE ALIGN AMPLIFIERS. The coarse align amplifiers are used to amplify and demodulate signals which represent the IMU gimbal angles commanded by the CDU's. During coarse alignment, the IMU is slaved to the CDU's so the alignment is completed when the Δ angle (IMU-CDU) equals 0 ± 1.5 degrees. The outputs of the coarse align amplifiers are supplied to the servo amplifiers in the stabilization loops which, in turn, coarsely align the IMU stable member.

2.4.6 FINE ALIGN TORQUING ELECTRONICS. The fine align torquing electronics is used for fine alignment of the stable member. The electronics contain current switches which are turned off and on by torquing commands and timing pulses from the AGC. Using data obtained from optical sightings, the AGC determines the number of command pulses required. The outputs of the current switches are in digital form and are supplied to the torque ducosyns of the 25 IRIG's.

2.4.7 ACCELEROMETER LOOPS. The accelerometer loops sense changes in acceleration due to thrust or drag forces applied to the spacecraft and provide change in velocity information to the AGC. The loops consist of three mutually perpendicular 16 PIP's on the stable member and associated electronics in the PSA. As acceleration is applied along the input axes of the 16 PIP's, signals are generated and used by the accelerometer loop electronics to generate digital feedback signals which act to restrain the 16 PIP pendulums. Incremental velocity, in the form of pulses, is supplied to the AGC and used in calculating velocity and position data. Timing pulses are supplied from the AGC to the accelerometer loop electronics which are used in the development of torquing signals for the accelerometer.

2.4.8 COUPLING DISPLAY UNITS AND ELECTRONICS. (See Figures 2-6 and 2-7.) The CDU's couple the IMU to the AGC and generate steering and alignment signals. The inertial subsystem contains three CDU's, one for each IMU gimbal. Each CDU contains resolvers, which are positioned either manually by the astronaut or automatically by the AGC. One of the major signals generated by the CDU's is the Δ angle (IMU-CDU) signal which is proportional to the angular difference between the IMU gimbal and CDU resolver positions. This signal can be used to control the position of the IMU or the CDU's, to display spacecraft attitude error or to develop attitude error signals for steering during thrusting maneuvers or for spacecraft attitude control. Relays are used to make the CDU connections necessary for operation in the different inertial subsystem modes. The CDU inputs and their functions are as follows:

a. IMU gimbal angle signals: indicate the angles of the inner, middle and outer gimbals.

b. Digital signals from the AGC: position the inner, middle and outer CDU resolvers.

c. Mode control signals: operate the relays in the CDU electronics so that different modes of operation can be entered.

d. CDU manual control: allows the CDU resolvers to be positioned manually during the manual CDU mode.

The CDU outputs and their functions are as follows:

a. Digital signals to the AGC: indicate changes in position of the CDU resolvers.

b. Δ angle (IMU-CDU) signal: represents the difference between the IMU gimbal angles and the CDU resolver angles. This signal is supplied to the resolver network for attitude control, to the flight director's attitude indicator, to the IMU control panel for display and to the coarse align amplifier for IMU torquing.

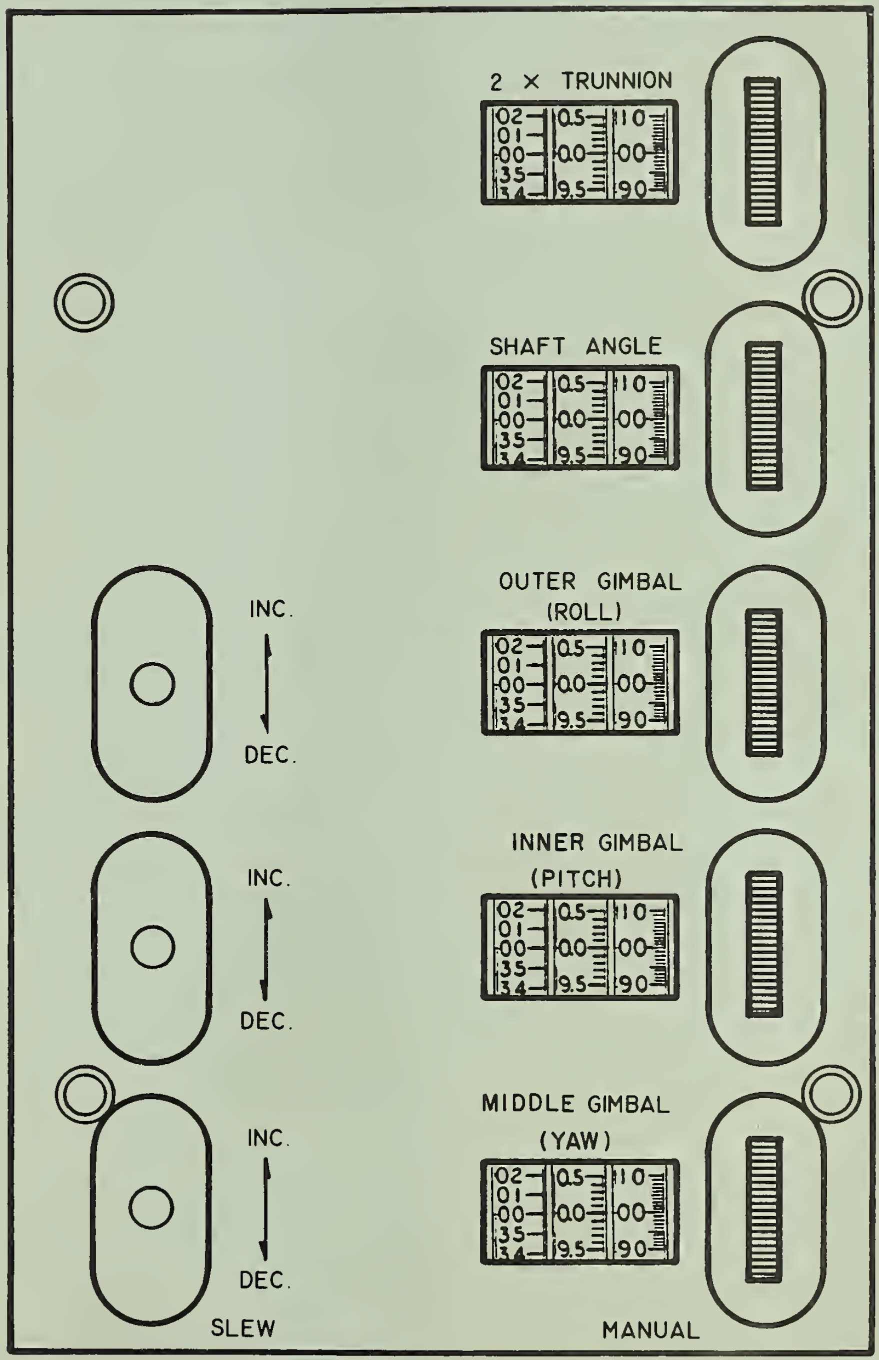


Figure 2-6. Coupling Display Unit Panel

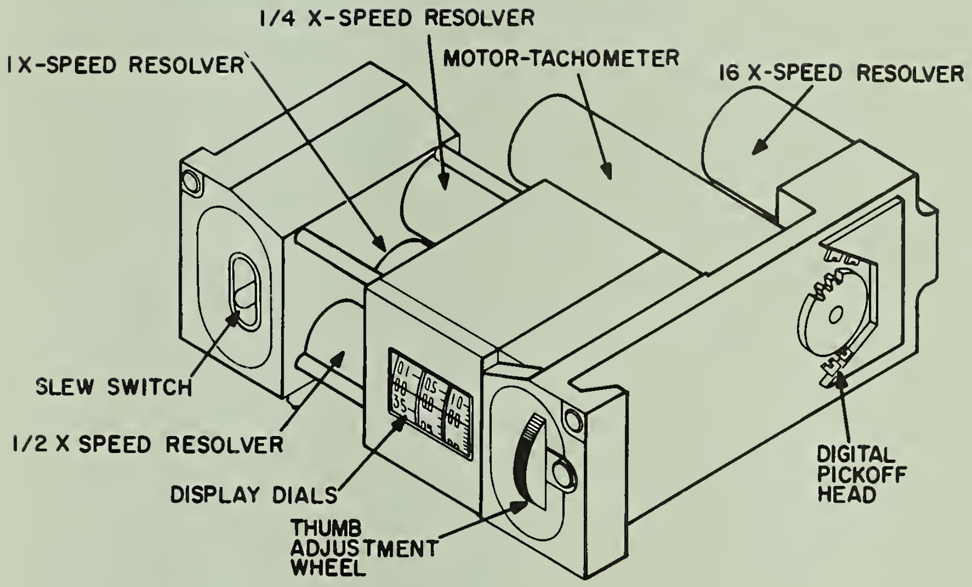


Figure 2-7. Coupling Display Unit

2.4.9 RESOLVING NETWORK. The resolving network transforms the Δ angle (IMU-CDU) signal into navigation base and spacecraft axes and supplies the resultant signals to the stabilization and control system. A resolver mounted on the outer gimbal axis and a fixed resolver are used in the resolver network.

2.4.10 LOWER DISPLAY AND CONTROL PANEL. The inertial subsystem display and control panels and their functions are as follows:

a. The IMU control panel: controls and indicates the mode in which the inertial subsystem is operating and displays the Δ angle (IMU-CDU) signals on a meter. (See Figure 2-8.)

b. The G & N indicator control panel: indicates IMU temperature control system mode of operation, provides a means of testing the temperature control circuits and contains windows for visual inspection of the IMU (see Figure 2-9).

c. The condition annunciator consists of condition lights which provide the navigator with subsystem status and detected subsystem errors.

2.4.11 MAIN DISPLAY AND CONTROL PANEL. Status of the inertial subsystem is supplied to the main display and control panel from the lower display and control panel so the astronaut can observe the subsystem conditions while reclining in his couch. Mode and power switching of the inertial subsystem is also implemented from the main display and control panel.

2.4.12 POWER SUPPLIES. The following power supplies, packaged in the PSA, are required to operate the inertial subsystem (Figure 2-10):

a. Pulse torque dc supply.

b. 800 cps IMU and CDU supply.

c. 3.2 kc ducosyn supply.

d. 3.2 pps temperature control reference.

e. -28 vdc supply.

f. 25.6 kc encoder excitation supply.

The power supplies operate on 28 volt dc prime power and are synchronized by pulses from the AGC. Local oscillators in the power supplies allow them to operate independent of the AGC. The outputs of the power supplies are monitored by the malfunction detection circuits.

2.4.13 MALFUNCTION DETECTION CIRCUITS. The malfunction detection circuits monitor the power supplies, temperature control and indicator circuits, stabilization loop electronics, accelerometer loop electronics and CDU electronics. When a malfunction occurs, the malfunction detection circuits produce a failure signal which is sent to the condition indicators on the master caution panel of the main display and control, the condition annunciator on the lower display and control panel and to the AGC. Table 2-1 lists the condition indicators and their functions.

2.4.14 MODE SWITCHING CIRCUIT. The mode switching circuit contains the relays and logic circuits used to make the connections required in the selection of the different inertial subsystem modes. Mode operation and the method of mode selection are described in Table 2-2.

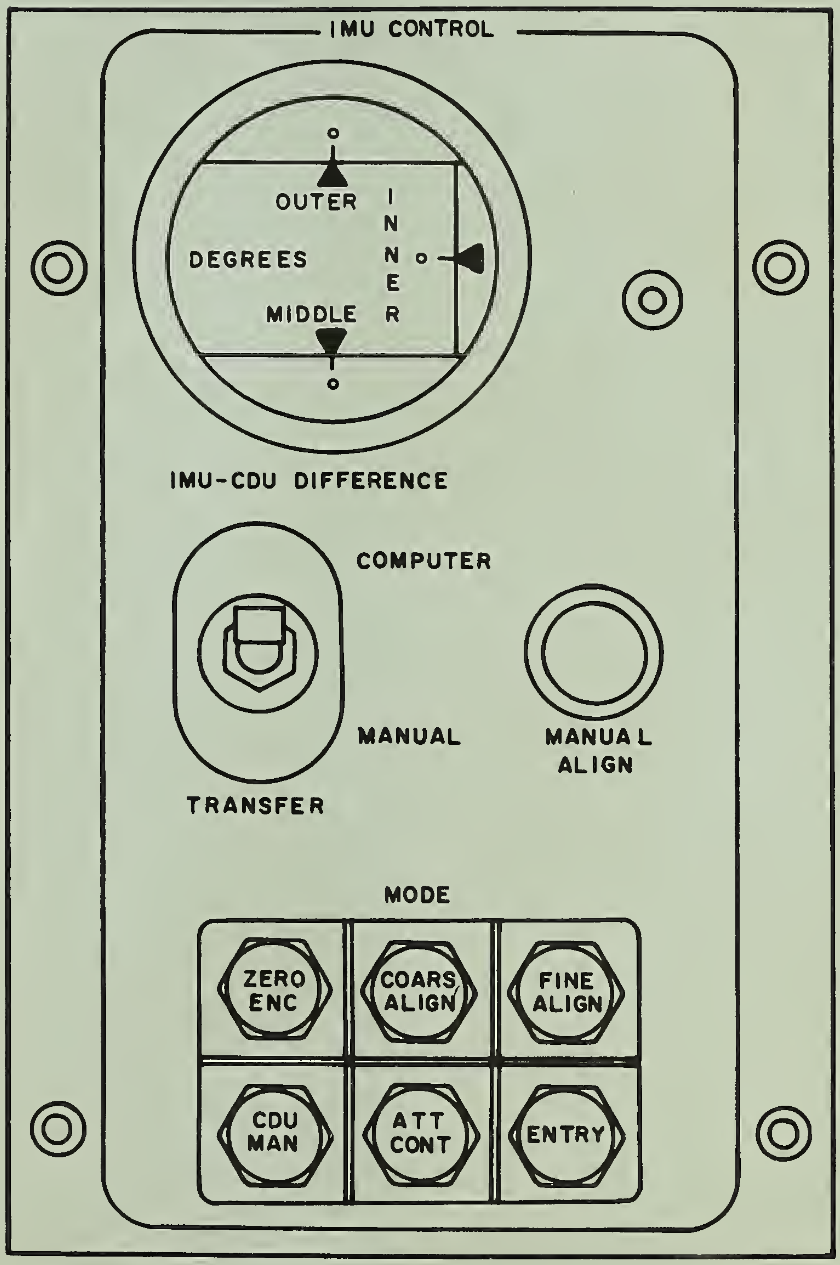


Figure 2-8. IMU Control Panel

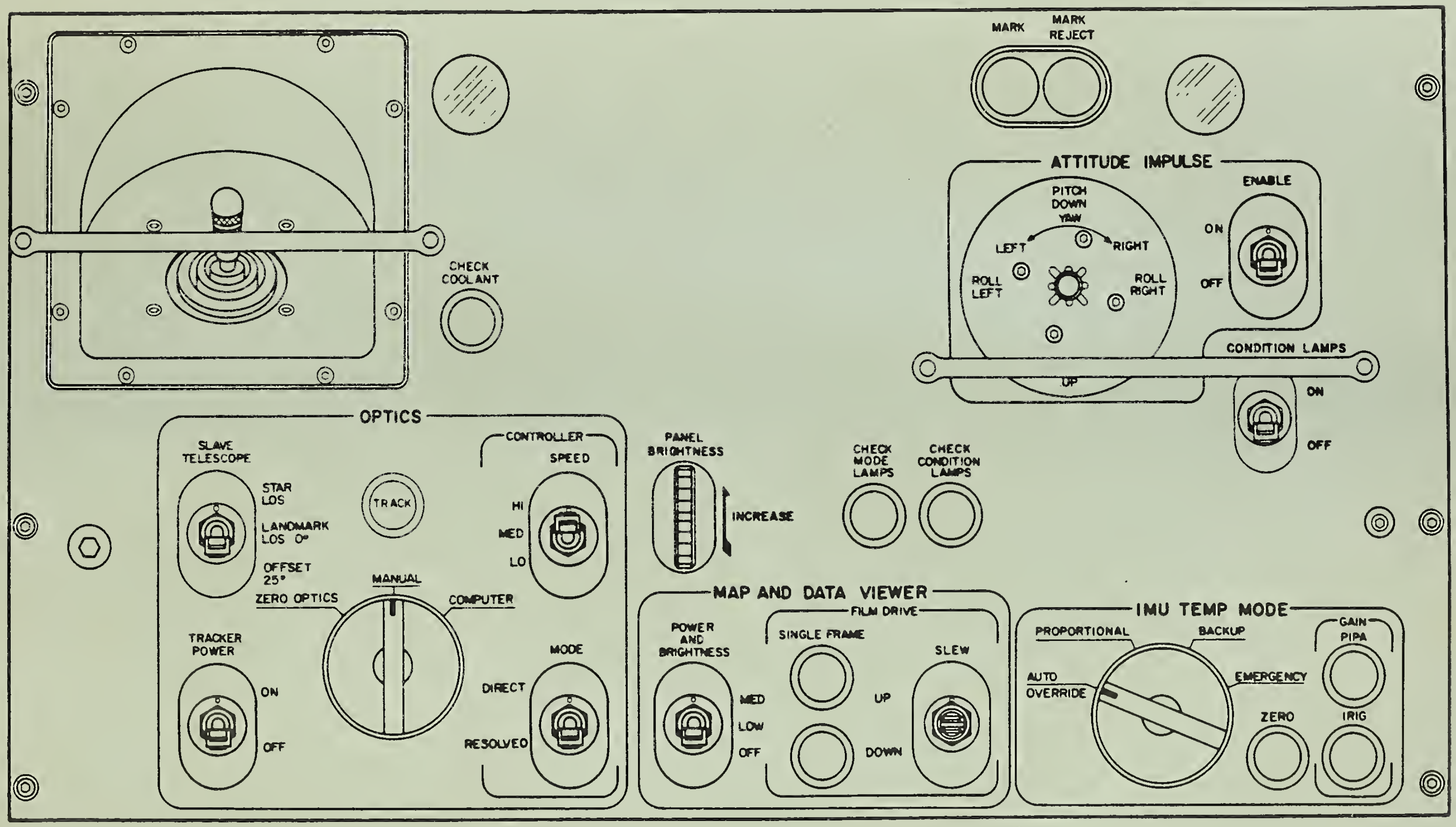


Figure 2-9. G & N Indicator Control Panel

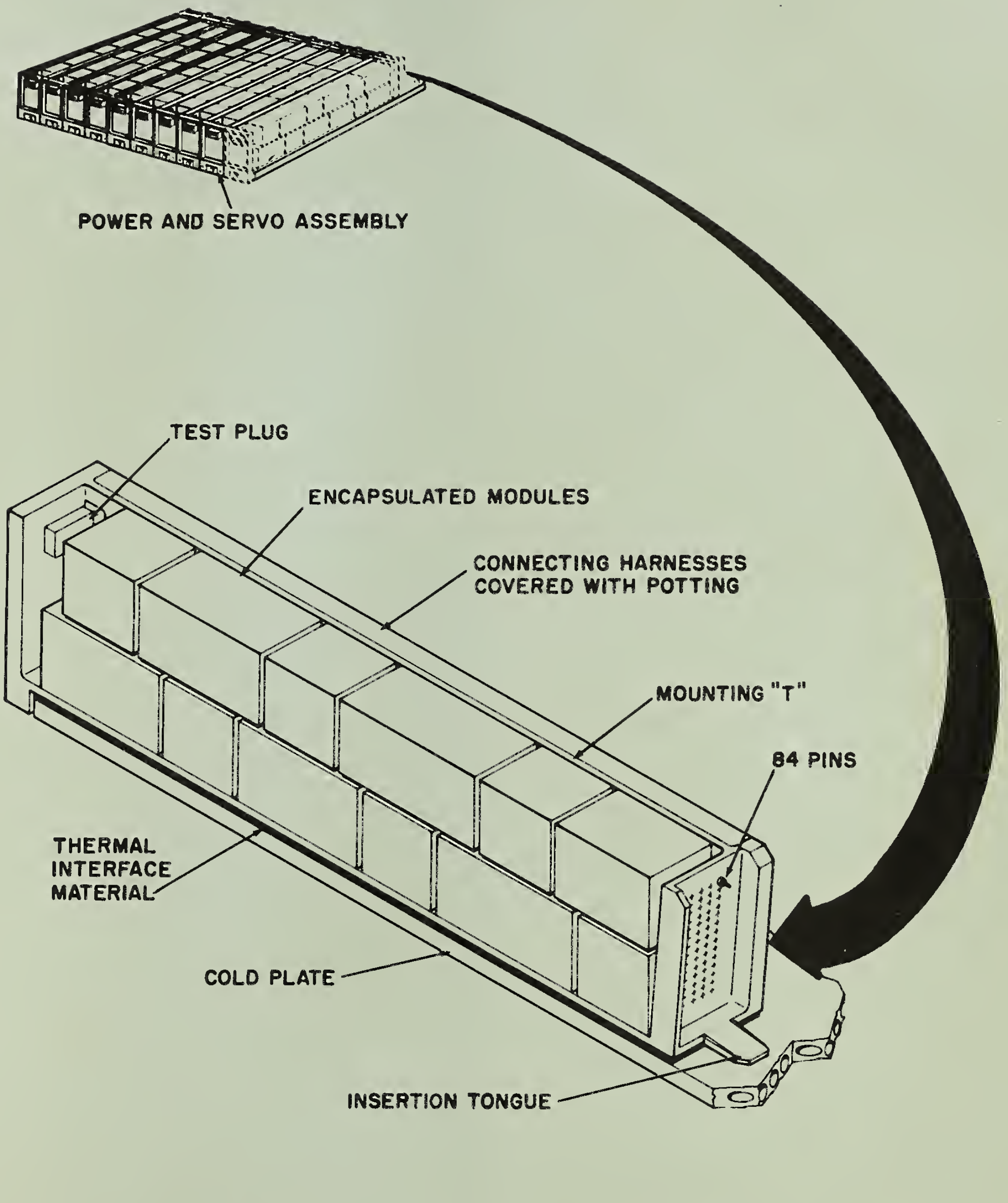


Figure 2-10. Power Servo Assembly Tray

Indicator	Location	Function
PGNS	Lower equipment bay	Causes: 1. CDU failure (also supplied to computer) a. CDU 25. 6 kc supply b. CDU motor excitation loss c. Inner, middle, outer CDU error 2. Accelerometer failure (also supplied to computer) a. X, Y, Z PIP error 3. IMU failure (also supplied to computer) a. 3200 cps power b. 800 cps wheel power c. Inner, middle, outer servo error 4. Program word errors, logic failures and power failure presented in Section IV.
IMU Temperature	Lower equipment bay caution/warning panel	Cause: 1. Deviations in IMU temperature greater than $\pm 5°$ from normal.
Gimbal lock	Lower equipment bay caution/warning panel	Cause: 1. Middle gimbal angle greater than $\pm 60°$.
IMU delay	Lower equipment bay	Cause: 1. IMU gyro wheels coming up to speed upon inertial subsystem turn-on.

Table 2-1. Inertial Condition Lights

Mode or Switch	Control	Function	Switch Location
IMU Standby	Manual	Applies power to the IMU temperature control circuitry and the gyro and accelerometer ducosyns for magnetic suspension.	Main display and control panel
IMU Operate	Manual	Applies power to inertial subsystem.	Main display and control panel right-hand console
Zero Encoder Mode	Manual or computer	CDU's are positioned at zero and the AGC encoder counters are initialized.	IMU control panel
Coarse Align Mode	Manual or computer	Positions the stable member to an approximate orientation as defined by CDU angles.	IMU control panel
Manual CDU Mode	Manual or computer	Gives the astronaut a backup mode with the capability of manually positioning the CDU's.	IMU control panel
Fine Align Mode	Manual or computer	Positions the stable member precisely to a reference frame defined by optical measurements.	IMU control panel
Attitude Control Mode	Manual or computer	IMU and CDU's generate attitude and steering commands which are supplied to the stabilization and control system.	IMU control panel
Entry Mode	Manual or computer	IMU and CDU's generate attitude and steering commands which are supplied to the stabilization and control system. (Command sensitivity is increased over attitude control panel).	IMU control panel
Manual Align Mode	Manual	Used in conjunction with manual CDU mode to slave the IMU to the CDU's.	IMU control

Table 2-2. Mode Switching

2.5 ISS EQUIPMENT MODES

The mechanization of the inertial subsystem modes (zero encoder, coarse align, fine align, manual CDU, attitude control and entry) is discussed in the following paragraphs. Upon entering a mode, the pushbutton on the IMU control panel lights and the mode switching relays complete the circuits. The mechanization of the ISS modes (zero encoder, coarse align and fine align) is identical for either AGC or manual control.

2.5.1 ZERO ENCODER. The purpose of this mode is to align the AGC registers that are associated with the ISS to the ISS CDU's (see Figure 2-11).

This is accomplished by applying a reference signal to the CDU resolvers that are normally connected to the IMU transmitter resolvers. The reference signal causes the resolvers to produce an error signal if the CDU shaft is not at its zero or null position. This error signal is applied to the CDU drive motor to drive the CDU to its zero position. A coarse-fine resolver network is used to zero the CDU's. The completion of CDU zeroing is indicated when the CDU encoder stops generating output pulses. While zeroing is in process, the zero encoder condition light on the condition annunciator panel is lighted by a command from the AGC. After a specified time, the AGC clears the registers associated with the ISS and extinguishes the zero encoder condition light.

2.5.2 COARSE ALIGN. In the coarse align mode, the stable member is oriented with respect to the navigation base as defined by the CDU settings. The IMU is slaved to the CDU's (see Figure 2-12). Coarse align can be commanded by either the AGC or the astronaut. The prerequisite requirements for AGC control are that the ISS and CSS be turned on and the CDU's zeroed. The CDU's are positioned automatically by the AGC. When AGC control is used, the navigator must enter the proper code numbers into the AGC keyboard. The AGC then commands coarse align, calculates the required gimbal angles and drives the CDU's to these angles. The alignment error signals, used to drive the stable member during coarse align, are generated in the CDU resolvers by the difference between the transmitting resolver (actual IMU gimbal angle) and the receiving resolver (desired CDU angle). The error signal is amplified and inserted into the stabilization loop, which then drives the torque motors on the IMU and slaves the IMU gimbal resolvers to the CDU resolvers. The alignment error signal is displayed to the navigator by the IMU-CDU difference meter located on the IMU control panel. The IMU gimbals are approximately aligned to the angles indicated by the CDU's.

2.5.3 FINE ALIGN. In the fine align mode, the stable member is precisely aligned to a coordinate frame determined by optical measurements. The process is performed in two steps: (1) optical measurements are taken sequentially on two fine align stars identified by the AGC and (2) torquing signals are calculated and issued by the AGC to the gyros to position the stable member of the IMU. The CDU's are slaved to the IMU. (See Figure 2-13).

During fine align, optical sightings are taken on two stars and the AGC receives optical and IMU gimbal angle input signals through the CDU's. Using the indicated sextant and IMU gimbal angles, the AGC transforms the star lines-of-sight into stable member coordinates and compares them with the star lines-of-sight components that would exist if the stable member were properly aligned. The differences are used to compute the angular rotation about each stable member axis which will carry the stable member into the correct orientation. The AGC gates the required number of torquing pulses through the fine align torquing electronics to each of the 25 IRIG's. The gyro torquing causes a signal in the stabilization loop which results in the stable member being rotated to the proper orientation. The change in gimbal angles is sensed by the CDU's and transmitted to the AGC by the encoders.

Upon completion of torquing, the stable member orientation is checked by resighting on the fine align stars. The AGC calculates and displays any misalignment and a final correction is made if necessary.

ZERO ENCODER MODE

Description of Signals:

1. Mode selection commands.
2. Resolver zero reference excitation applied during zero encoder.
3. Resolver output which is proportional to CDU displacement from the zero reference position. Used to position CDU to its zero reference position.
4. Encoder output which indicates changes in CDU position.
5. Error signal generated by the gyros due to spacecraft movement.
6. Torquing signals used to drive the IMU gimbals. The stable platform remains inertially referenced.

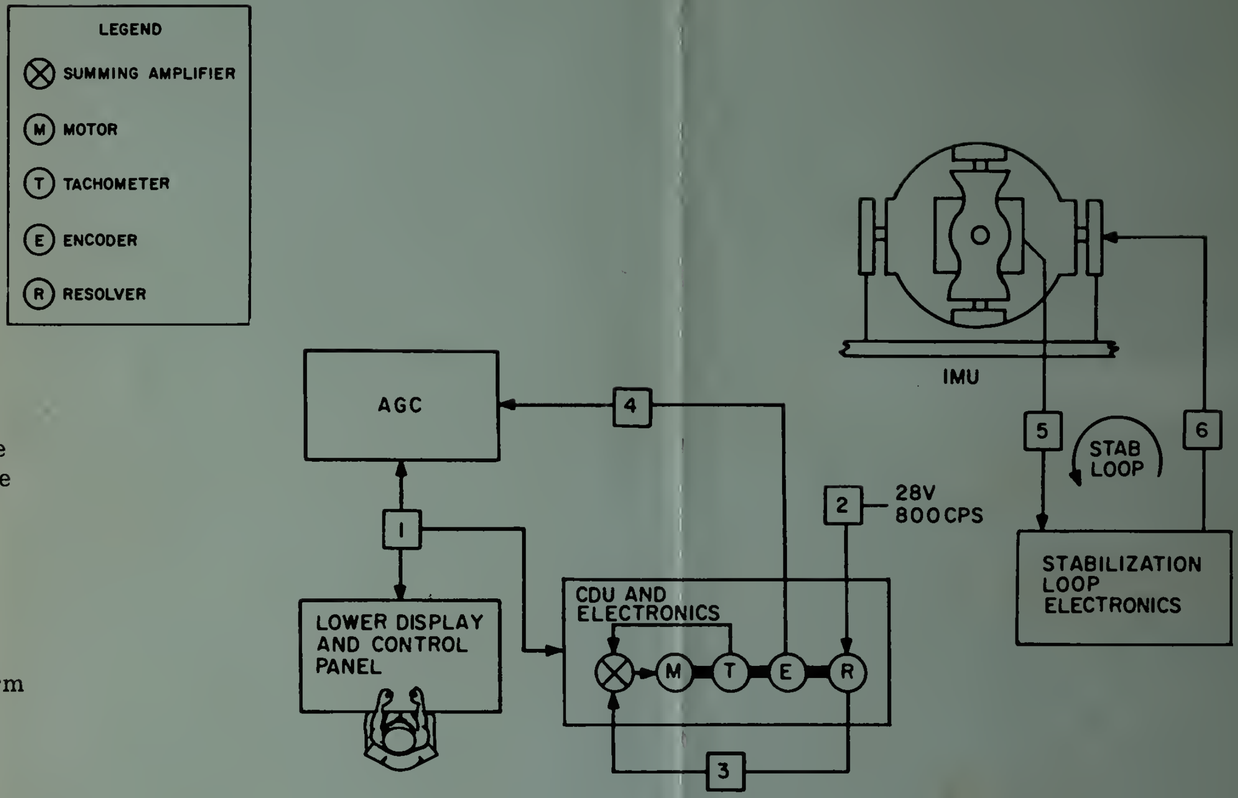


Figure 2-11. Zero Encoder Mode

COARSE ALIGN MODE

Description of Signals:

1. Mode selection commands.

2. Positions the CDU's at the required angles.

3. Encoder output which indicates changes in CDU position.

4. Alignment error signal. This Δ angle (IMU-CDU) signal is the difference between the IMU gimbal angles and the CDU angles.

5. Amplified error signal which is injected into the stabilization loops.

6. Torquing signals used to drive the IMU torque motors.

7. Error signal generated by the gyros due to stable member motion.

8. Resolver output which is proportional to the IMU gimbal angles and fed back to the CDU's.

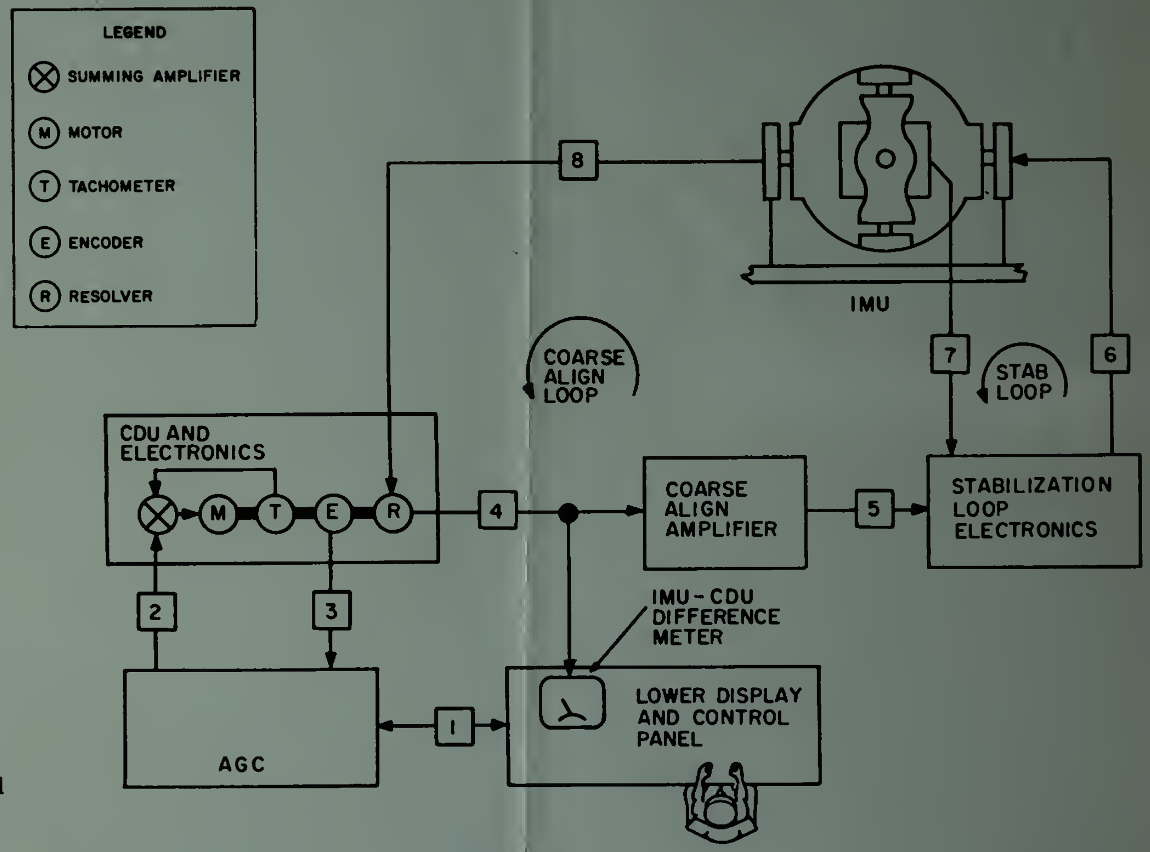


Figure 2-12. Coarse Align Mode

FINE ALIGN MODE

Description of Signals:

1. Mode selection commands.

2. Timing and control pulses supplied by the AGC and used to generate torquing pulses in the fine align torquing electronics.

3. Torquing pulses used to torque the gyro floats and generate error signals in the stabilization loop.

4. Error signal generated by the gyros due to the torquing pulses.

5. Torquing signals used to drive the IMU torque motors.

6. Resolver output which is proportional to the IMU gimbal angles.

7. Error signal, difference between IMU gimbal angle and CDU angles. Used to slave CDU's to IMU gimbal angles.

8. Encoder output which indicates changes in IMU gimbal angle.

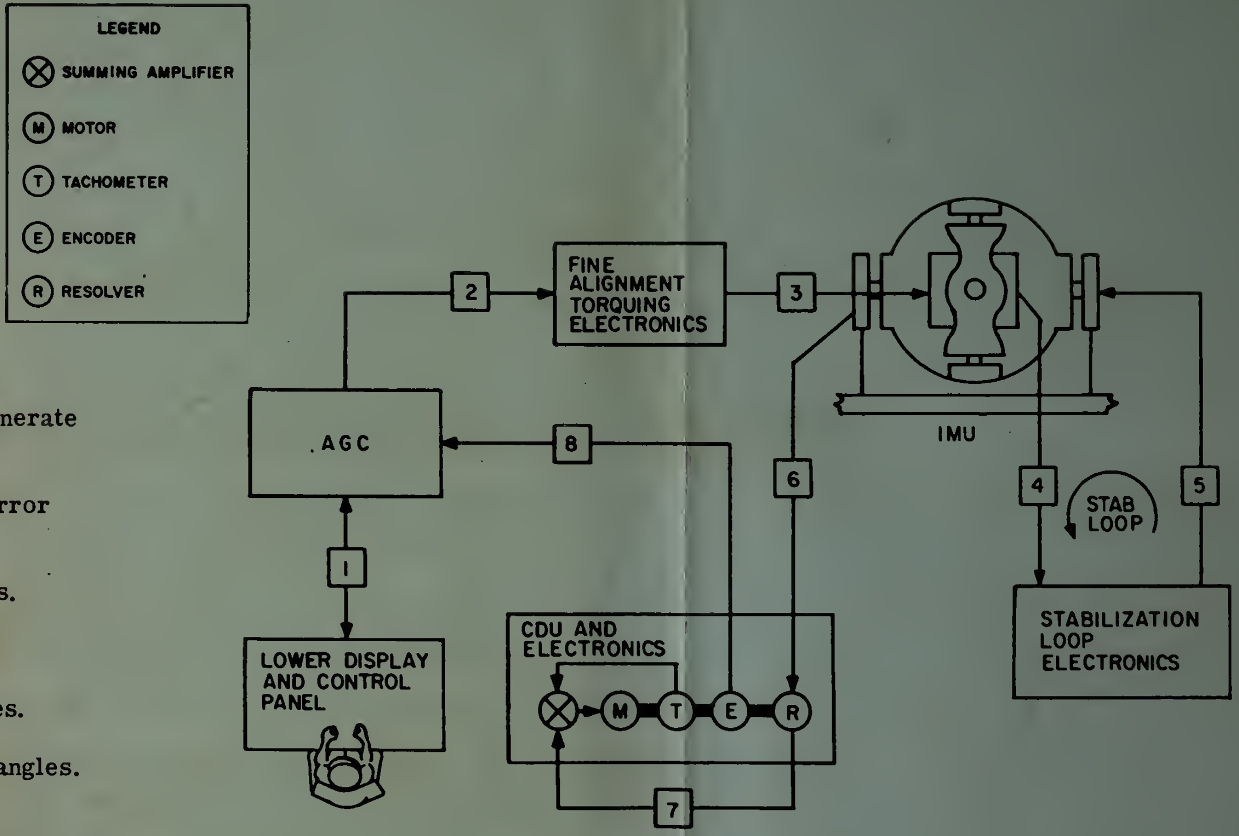


Figure 2-13. Fine Align Mode

2.5.4 CDU MANUAL. The CDU manual mode provides the astronaut with the capability to perform a coarse alignment of the IMU manually. (See Figure 2-14.)

To align the IMU manually, the ISS must be in the CDU manual mode with the manual align pushbutton pressed. The CDU's are then manually positioned by either the CDU slew switch or the thumbwheel to the desired angle. At this time the manual align pushbutton is depressed which causes the ISS to enter the coarse align configuration. Repositioning the CDU's cause an error signal to be developed at the CDU resolver and this error signal is applied through the coarse align amplifier and stabilization loop electronics to torque the IMU gimbals approximately to the CDU angle setting.

2.5.5 ATTITUDE CONTROL. This mode reorients the spacecraft by generating an attitude error signal that keeps the IMU gimbal and CDU angles equal. The navigator can control the attitude of the spacecraft by controlling the position of the CDU's. The attitude control mode can be established automatically by the AGC or manually by pressing the attitude control button on the IMU control panel. Figure 2-15 shows the attitude control mode used in generating the attitude error signal. The IMU is fine aligned to a desired orientation and held space referenced with the stabilization loop.

The IMU gimbal angles necessary for the required spacecraft attitude are normally set into the CDU's by the AGC. The changes in CDU angles are fed back to the AGC by the encoder. Attitude error signals (IMU-CDU difference), generated in the CDU's, consist of the sine of the differences between the IMU gimbal transmitter resolver angles and their respective CDU receiver resolver angles. The resolver network transforms the attitude error signal from IMU gimbal axes (inner, middle and outer) into navigation base axes and spacecraft axes. The attitude error signals in spacecraft axes are used by the stabilization and control system to reposition the spacecraft. Repositioning the spacecraft changes the IMU gimbal angles. When the IMU gimbal and CDU angles are equal, the repositioning maneuver is completed.

The attitude error signal from the CDU's to control the spacecraft can be removed in the SCS by using the rotation controls. The two rotation controls generate roll, pitch and yaw signals and are located on the arm rests of the couches or the lower display and control panel.

The G & N sync switch on the display and control panel allows the pilot to: (1) slave the CDU's to the IMU gimbal angles during spacecraft reorientation and (2) establish an attitude-hold condition after the spacecraft is reoriented (see Figure 2-16). When the G & N sync switch is turned on, the inertial subsystem enters the manual CDU mode which removes excitation from the CDU motors to prevent changing the CDU settings. The spacecraft is then maneuvered by the rotation control to a new orientation. When the rotation control is displaced from null and the SCS is in a G & N mode, the ISS will enter the fine align mode.

With the SCS relay K1 energized and the ISS in the fine align mode, the CDU's will be slaved to IMU gimbal angles. When K1 is deenergized, the spacecraft is held at the new orientation by the attitude control mode circuits.

The attitude control mode is also used during thrusting maneuvers. When the ISS is aligned, in the attitude control mode, and the SCS is in the G & N attitude control mode, the G & N system controls the spacecraft attitude by activating the RCS jets. When the SCS is in the G & N Δ V mode, the ISS error signals for pitch and yaw are routed to the SPS engine gimbals. The roll attitude error is routed to the RCS roll jets. The AGC monitors the IMU accelerometers and develops torquing signals to the CDU's, which then develop attitude error signals, which are applied to the SPS engine gimbals, to guide the spacecraft along the calculated velocity vector. The AGC also develops the engine on-off signals.

CDU MANUAL MODE

Description of Signals:

1. Drive signal which is controlled by the navigator and used to position the CDU's.

2. Alignment error signal. This Δ angle (IMU-CDU) signal is the difference between the IMU gimbal angles and the CDU angles.

3. Amplified error signal which is injected into the stabilization loops.

4. Gimbal torquing signal used to drive the IMU torque motors.

5. Error signals generated by the 25 IRIG's due to motion of the stable member.

6. Resolver output which is proportional to the IMU gimbal angles and which is fed back to the CDU's.

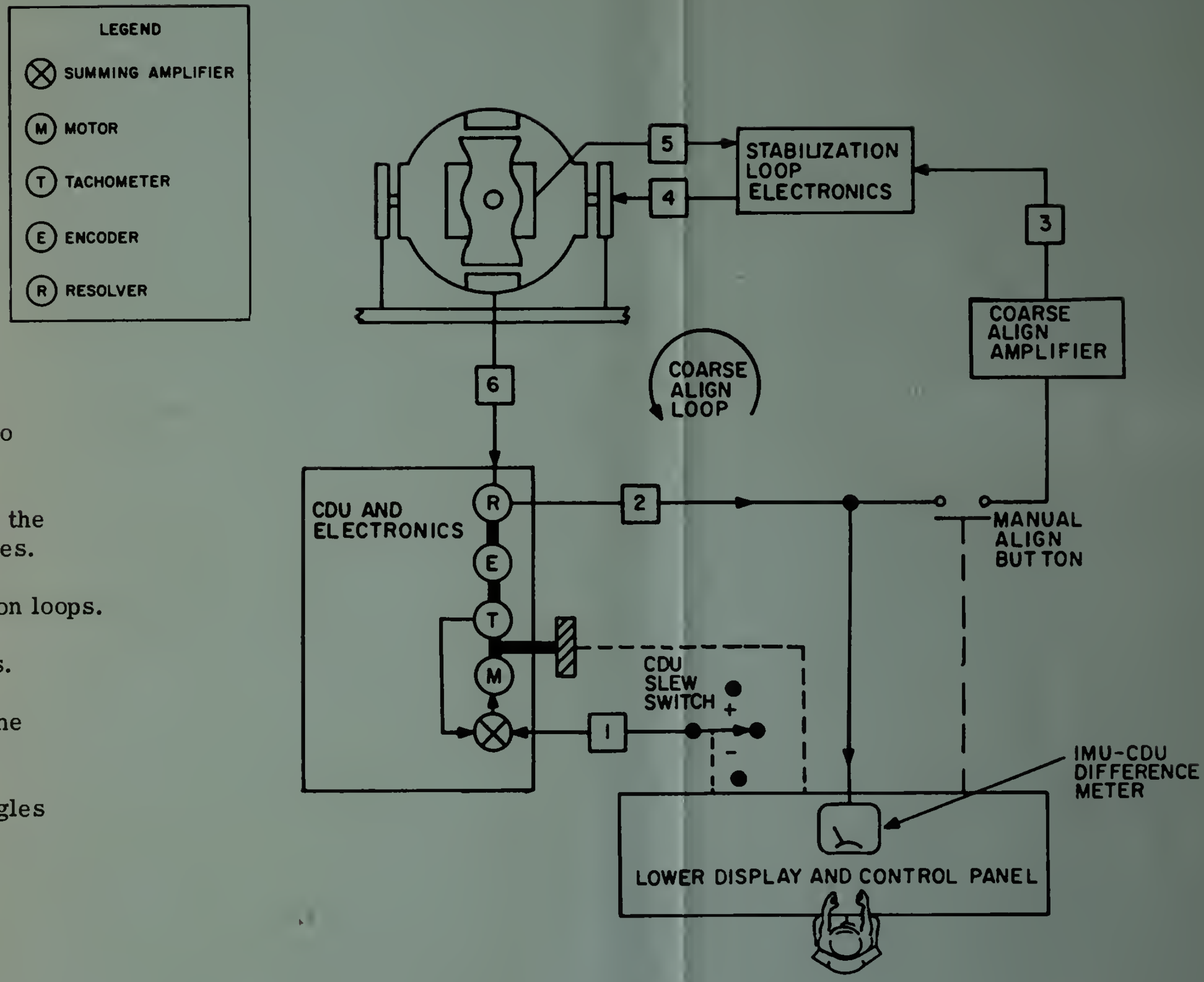


Figure 2-14. CDU Manual Mode

ATTITUDE CONTROL MODE

Description of Signals:

1. Controls selection of AGC programs; provides information to display and control panel which indicates the mode of operation of the G & N system.
2. Positions the CDU to a given angle and causes an error signal in the attitude control loop.
3. Encoder output which indicates changes in the CDU setting.
4. Attitude error signal. Difference between the IMU gimbal angles and the CDU angles.
5. Attitude error signal resolved into spacecraft axes.
6. Command to the reaction control system.
7. Signal to turn the reaction jets on and off.
8. Rotational motion of the spacecraft about the stable member.
9. Rotational motion of spacecraft sensed by the stabilization and control system rate gyros.
10. Error signal generated by the 25 IRIG's due to stable member motion.
11. Torquing signal used to drive the IMU torque motor and reposition the stable member.
12. Resolver output (1X) which is proportional to the sine of the IMU gimbal angle.

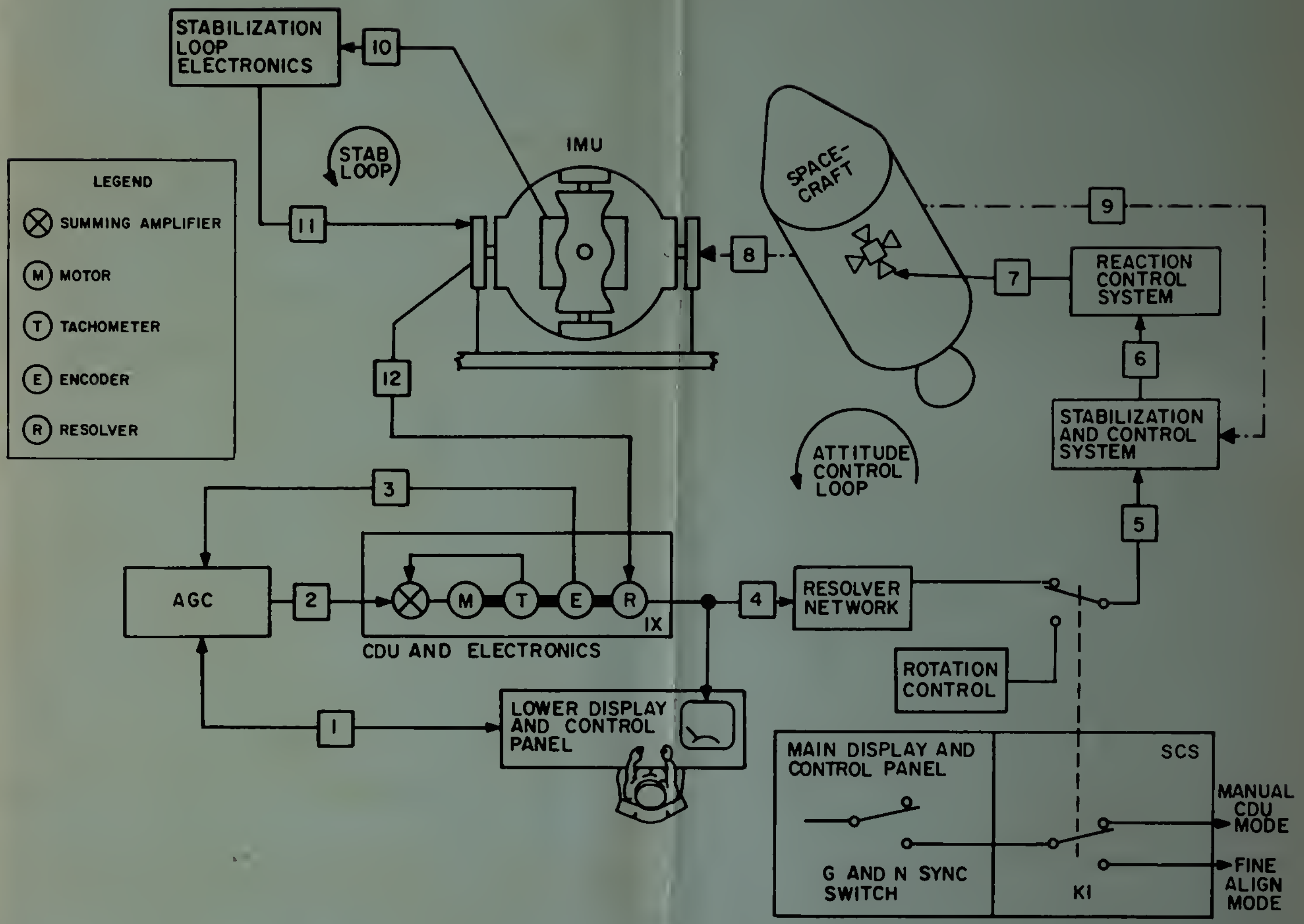


Figure 2-15. Attitude Control Mode

THRUST MANEUVER

Description of Signals:

1. Controls selection of computer programs; provides information to display and control panel which indicates the guidance and navigation modes of operation.
2. Positions the CDU to a given angle and causes an error signal in the velocity steering loop.
3. Encoder output which indicates changes in the CDU setting.
4. Attitude error signal used for steering. Sine of the difference between the IMU gimbal angle and CDU angle.
5. Attitude error signal resolved into spacecraft axes.
6. Engine on and off discrete issued by the AGC to turn on and shut off service propulsion engine.
7. Commands for operation of the service propulsion system.
8. Signal to actuate the service propulsion engine gimbal servos and the propellant control valves.
9. Rotational motion of the spacecraft about the stable member and velocity changes of the spacecraft.
10. Rotational motion sensed by the stabilization and control system rate gyros.
11. Error signal generated by the gyro due to stable member motion.
12. Torquing signal used to drive the IMU torque motor and reposition the stable member.
13. Gimbal 1X resolver output.
14. Accelerometer output proportional to the specific force applied to the IMU.
15. Pulsing signal to accelerometer to return pendulum to a null position.
16. Change-in-velocity pulses accumulated by the AGC.
17. Timing pulses required for operation of the accelerometer loop.

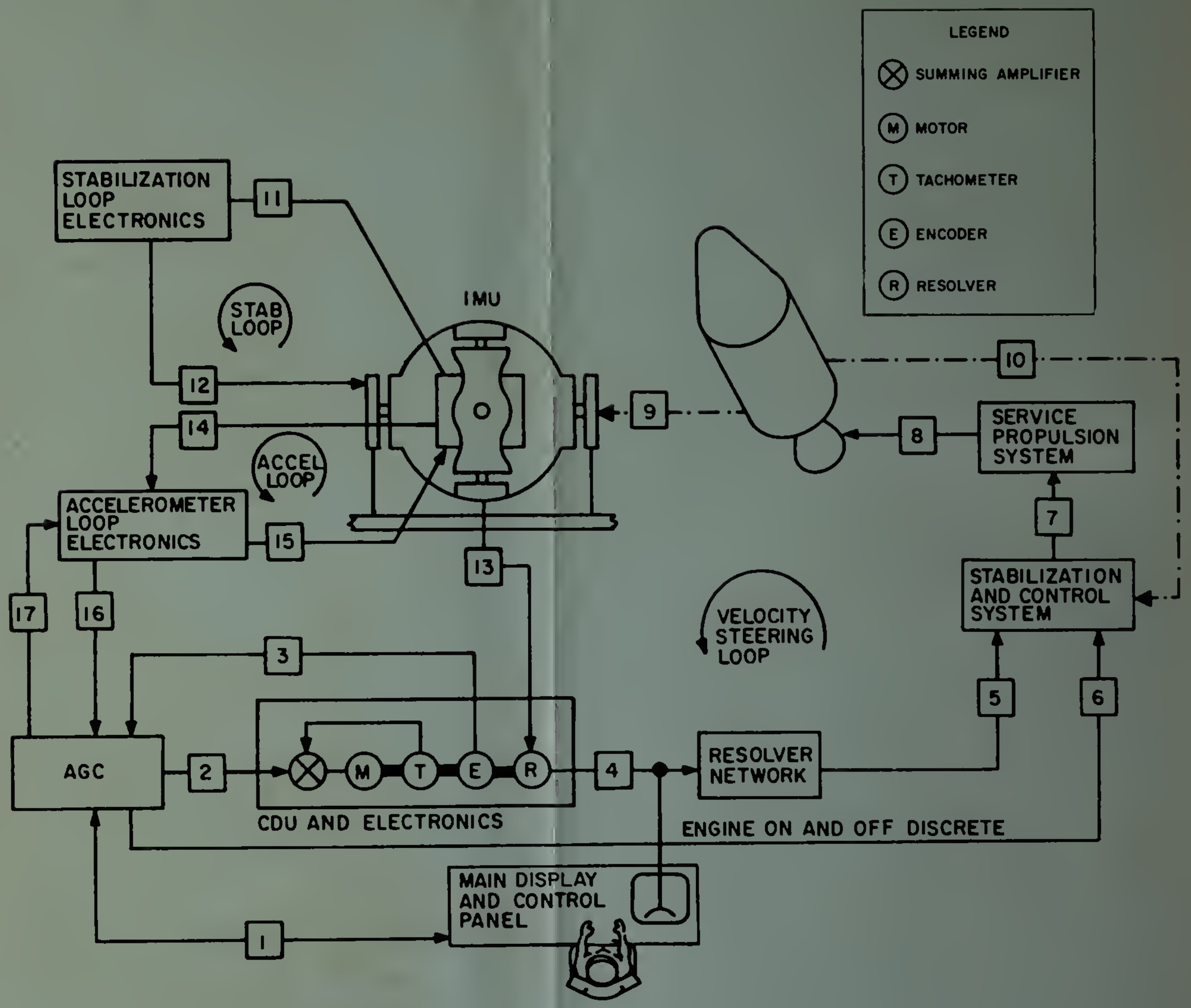


Figure 2-16. Thrust Maneuver

2.5.6 ENTRY. The entry control mode, used during the mission entry phase, controls the orientation of the command module lift/drag ratio. The entry control mode is established automatically by the AGC or manually by pressing the entry pushbutton on the IMU control panel. Lift and drag are varied by rolling the spacecraft about the roll entry axis which is parallel to the navigation base X axis. The entry "corridor", in which the command module must travel, is defined by the angle at which the spacecraft enters the atmosphere. An uncontrolled skipout will result if the command module does not enter the atmosphere at a steep enough angle (overshoot). If the command module enters the atmosphere at too steep an angle (undershoot), excessive g-loads will result. Due to the critical nature of the entry phase, it is necessary that the attitude control loop respond rapidly to an error signal. The response of the loop is improved during entry by connecting the 1X IMU outer gimbal resolver to the CDU 16X resolver. This connection decreases, by a factor of 16, the time required to achieve a given angle commanded because the AGC output required is only 1/16 the normal output for a given angle. The mechanization of the entry mode is similar to the attitude control mode. (See Figure 2-17.)

2.6 ISS TEMPERATURE CONTROL MODES

The mechanization of the four ISS temperature control modes (auto-override, proportional, backup and emergency) is illustrated in Figure 2-18 (ISS Temperature Control) and discussed in the following paragraphs.

2.6.1 AUTO-OVERRIDE. The auto-override mode provides automatic switching from proportional operation to emergency operation should the IMU temperature go out of tolerance.

During auto-override, the IRIG control sensors provide heater current regulation, as long as the temperature is within tolerance. The control heaters and emergency heaters operate in parallel, during this mode, to maintain the temperature. The blower speed control varies the blower speed inversely to heater current (as heater current goes up, blower speed goes down). The temperature indicating sensors and circuitry provide a dc low to Relays K1 and K2 as long as the temperature remains within tolerance to hold the relays energized. As long as K1 is energized, the IMU temperature no-go indicators will not light. As long as K2 is energized the temperature control operates as described above. When the temperature goes out of tolerance the relays deenergize, the indicators light and temperature control is switched to the emergency heater control circuitry through the deenergized contact of K2. The emergency heater control consists of two mercury thermostats on the platform and control circuitry necessary to turn on and off the emergency heaters.

2.6.2 PROPORTIONAL. The proportional mode operates the same as auto-override except that there is no automatic switching capability.

2.6.3 BACKUP. The backup mode eliminates the temperature control sensors and the proportional temperature control circuitry from the loop and uses the indicating sensors for temperature control sensors. The temperature indicating circuitry is modified so that when the temperature is below the upper temperature limit, the temperature indicating circuitry output is always a dc low. This output signal is applied to the heater control circuitry. The emergency heater control circuitry then controls the temperature regulation.

2.6.4 EMERGENCY. The emergency mode uses only the emergency heater and control circuitry to maintain temperature.

ENTRY MODE

Description of Signals:

1. Controls selection of AGC programs; provides information to display and control panel which indicates the mode of operation of the G & N system.
2. Positions the CDU to a given angle and causes an error signal in the attitude control loop.
3. Encoder output which indicates changes in the CDU setting.
4. Attitude error signal. Difference between the IMU gimbal angles and the CDU angles.
5. Attitude error signal resolved into spacecraft axes.
6. Command to the reaction control system.
7. Signal to turn the reaction jets on and off.
8. Rotational motion of the spacecraft about the stable member.
9. Rotational motion of spacecraft sensed by the stabilization and control system rate gyros.
10. Error signal generated by the 25 IRIG's due to stable member motion.
11. Torquing signal used to drive the IMU torque motor and reposition the stable member.
12. Resolver output (16X) which is proportional to the sine of the IMU gimbal angle.
13. Change-in-velocity pulses accumulated by the AGC.
14. Timing pulses required for operation of the accelerometer loop.
15. Pulsing signal to accelerometer to return pendulum to a null position.
16. Accelerometer output proportional to the specific force applied to the IMU.

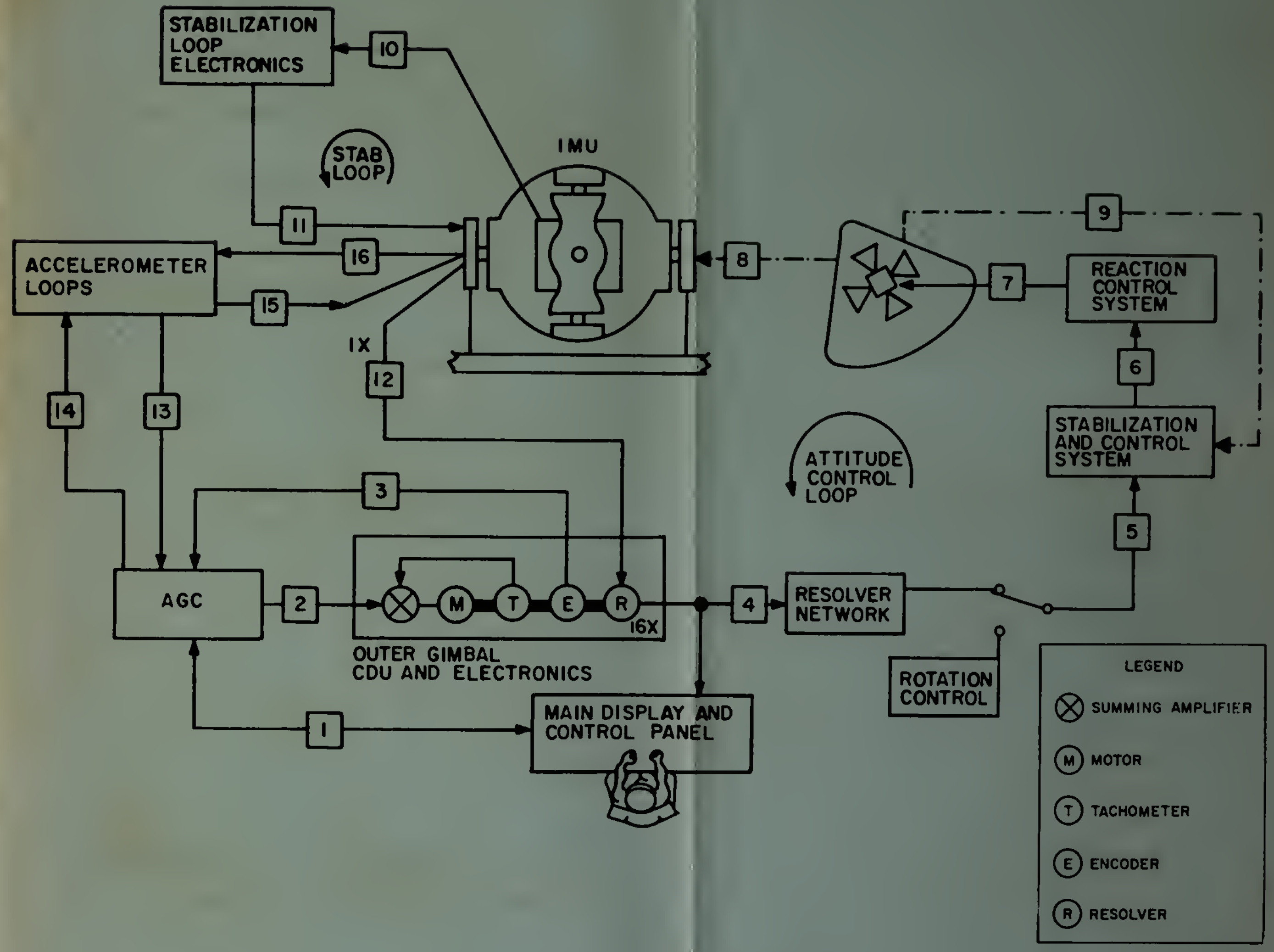


Figure 2-17. Entry Mode

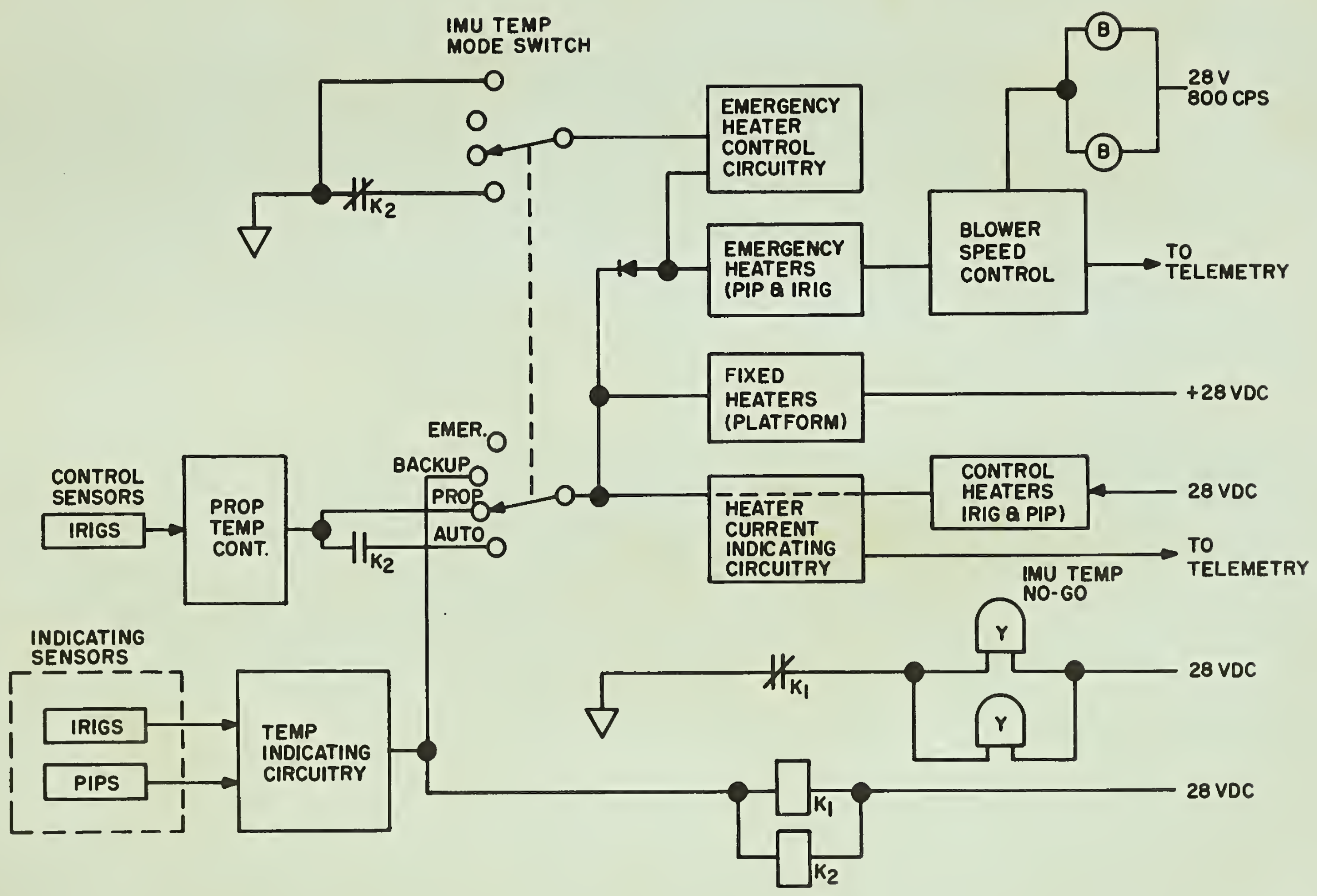


Figure 2-18. ISS Temperature Control

2.7 SUMMARY

The ISS maintains an inertial reference from which spacecraft attitude and velocity changes are measured. The ISS has the capability of controlling spacecraft attitude and velocity changes. The ISS consists of:

a. Navigation Base (NB)

b. Inertial Measurement Unit (IMU)

c. Coupling Display Units (CDU's) (three)

d. Power and Servo Assembly (PSA)

e. Lower Display and Control Electronics

f. IMU Control Panel

g. G & N Indicator Control Panel

The IMU consists of a stable member with three degrees of freedom. Mounted on the IMU stable member are: three stabilization gyros (25 IRIG's), three accelerometers (16 PIP's), one ADA and certain critical preamplifiers. Two ADA's are also mounted on the middle gimbal sphere. Three coupling display units monitor the IMU gimbal angles and provide the angles to the AGC and the astronaut. The power and servo assembly (PSA) contains the support electronics for the ISS.

The ISS modes of operation are:

a. Standby: IMU temperature control and gyro magnetic suspension is maintained.

b. Zero encoder: CDU's are positioned at zero and the AGC encoder counters are initialized.

c. Coarse align: the stable member is positioned by the CDU's.

d. Fine align: AGC positions the stable member and the CDU's repeat the IMU gimbal angles.

e. Manual CDU: The astronaut controls CDU position and IMU follows.

f. Attitude control: IMU maintains an inertial reference and CDU's provide steering signals to the stabilization and control system to control spacecraft attitude.

g. Entry: IMU provides steering signals to stabilization and control system to control the entry profile.

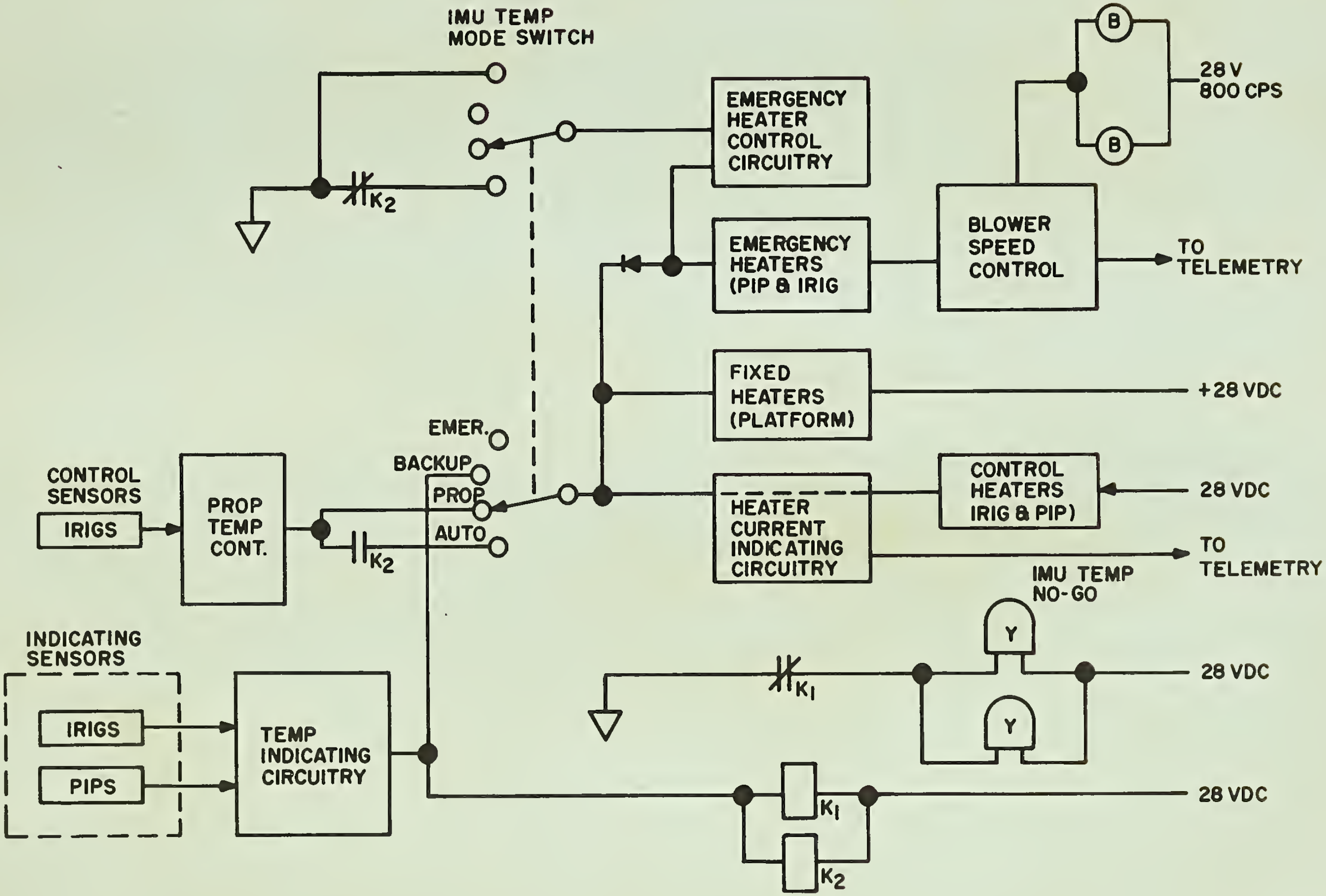


Figure 2-18   ISS Temperature Control

REVIEW QUESTIONS FOR SECTION II

1. What are the two basic functions of the ISS?

2. The IMU gimbal angles are transferred to the AGC through what major component?

3. The stable member uses what type of stabilization gyro to maintain the inertial reference?

4. During coarse align, how is the IMU stable platform positioned?

5. During fine align, how is the IMU stable platform positioned?

6. During the attitude control mode, how are the ISS steering signals developed?

7. What is the purpose of the auto-override temperature control mode?

8. Show the relationship between the sets of axes listed below:

a. Spacecraft

b. Navigation base

c. IMU gimbal axes at zero degrees

SECTION III

OPTICAL SUBSYSTEM

INTRODUCTION

This section discusses the purpose of the OSS, describes the OSS hardware, classifies the OSS into functional blocks, discusses the functional blocks and explains the OSS modes of operation.

3.1 OSS PURPOSE

The optical subsystem enables the astronaut to make optical sightings on celestial objects by means of a telescope and sextant. These sightings are used in updating this spacecraft's position and velocity and in aligning the IMU. The celestial bodies serve as the primary reference for navigation of the spacecraft when using the G & N system.

The taking of optical sightings is a semi-automatic operation and requires the astronaut to point the optical instruments. If the celestial objects cannot be acquired by operating the optical controls alone, the astronaut must change the attitude of the spacecraft by commanding roll, pitch and yaw motion with the spacecraft rotation control.

At the instant the optical sighting is taken, the time of sighting, the angles of the optical instruments and the IMU gimbal angles if the ISS is enabled, are recorded by the AGC. Data pertaining to the location of the celestial objects and programs for navigational calculations have been stored in the AGC. The navigational measurements can be accomplished during earth orbit by measuring the angles to landmarks with the telescope. Midcourse navigation is accomplished by measuring the angle between a landmark and a star with the sextant. The IMU is aligned during flight by measuring the angle between the navigation base and each of two stars with the sextant. Optical sighting data is also used in IMU prelaunch alignment.

In case of a failure in the optics electronics, the astronaut may be required to operate the telescope manually with the universal tool and read the angles off counters on the telescope axes. In such emergencies, the astronaut calculates, with possible assistance from the ground, a navigational fix and velocity correction.

3.2 OSS EQUIPMENT

The optical subsystem consists of the following equipment (see Figure 3-1):

a. Navigation Base (NB)

b. Optical Assembly

c. Coupling Display Unit (CDU) (two required)

d. Power Servo Assembly (PSA) (portions)

e. G & N Indicator Control Panel (portions)

f. Optical Panel

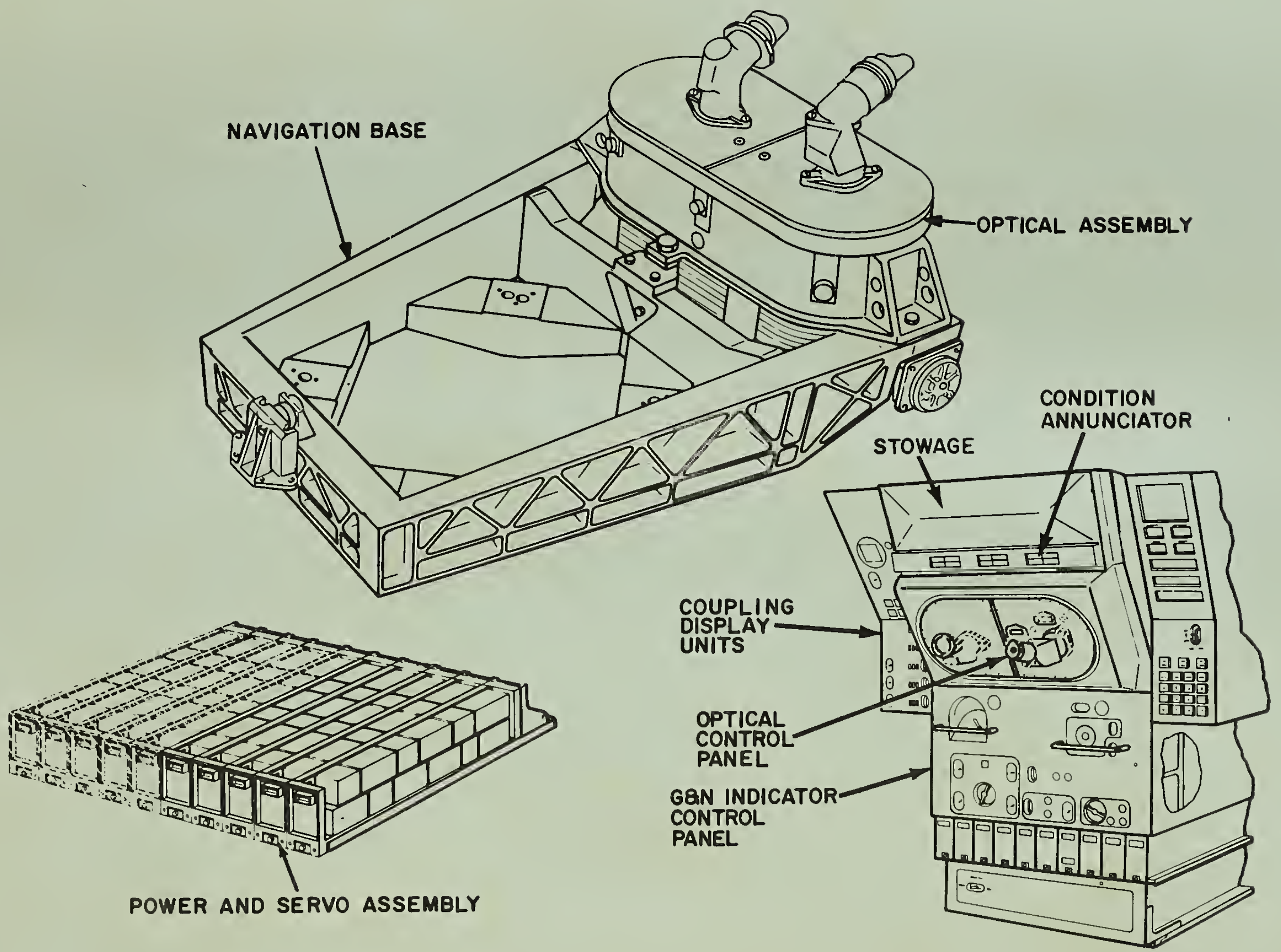


Figure 3-1. Optical Subsystem Equipment

3.3 OSS FUNCTIONAL BLOCKS

For the purpose of this explanation, the optical subsystem equipment is divided into functional blocks as shown in Figure 3-2. The operation and interrelationship of these blocks are described in the following paragraphs.

3.3.1 NAVIGATION BASE. The navigation base is used as a holding fixture to provide a rigid support of the optics with respect to the IMU. The optics are fixed in precise alignment to the navigation base. Flexible sealing at the spacecraft opening is supplied by a bellows assembly around the optical instruments (see Figure 3-3).

3.3.2 TELESCOPE. The telescope is mounted beside the sextant to permit parallel lines of sight through an opening in the spacecraft. The telescope, with its large field of view, is used as an aid to the sextant for coarse acquisition in midcourse navigation, for in-flight IMU coarse alignment sightings, and for measuring angles to landmarks during earth orbit.

The telescope is a refracting type and has magnification power of 1X with a field of view of 60 degrees. The telescope has two degrees of rotational freedom (see Figure 3-4) with the shaft axis and trunnion axis defining the axes of rotation. See Figure 2-2 for relationship of optical axes to spacecraft axes. Continuous rotation is physically possible about the shaft axis, which is fixed with respect to the spacecraft, but in operation, is limited to the shaft movement of the sextant. Rotation about this axis defines the shaft angle (A_s). Continuous rotation is also possible about the trunnion axis, which is perpendicular to the shaft axis. Rotation about this axis defines the trunnion angle (A_t). A prism, located on the trunnion axis, is rotated to reflect the image into the objective lenses of the telescope. Because of obstructions caused by spacecraft airframe, the line of sight (LOS) of the trunnion has a useful range of approximately 57 degrees. By rotating the telescope about the trunnion and shaft axes, a maximum field of approximately 114 degrees can be viewed. To control the motion of the telescope line of sight, shaft and trunnion drive rates are normally supplied to the sextant drive circuits, which position the sextant shaft and trunnion (see Figure 3-5). During normal operation, the shaft and trunnion of the sextant and telescope are slaved together. To acquire objects outside the 114 degree field of view, the attitude of the spacecraft must be changed. The shaft and trunnion angles can be read directly from the telescope by counters mounted on the face of the optical panel. A tool is also provided so that the trunnion and shaft angles can be manually positioned. A cutaway of the telescope is shown in Figure 3-6.

3.3.3 SEXTANT. The sextant is more precise than the telescope and is used primarily during the midcourse phase for measurement of angles between a landmark and a star or for sighting each of two stars for fine alignment of the IMU. The sextant has two lines of sight, landmark and star. The landmark line of sight (landmark LOS) is fixed with respect to the spacecraft. To align the landmark LOS to a particular landmark, the attitude impulse control, which makes small changes in the spacecraft attitude rates, and the spacecraft rotation control are used. The star line of sight (star LOS) has two degrees of freedom and operates similarly to the telescope in that it can scan a field of approximately 114 degrees. Figure 3-4 shows the sextant's shaft and trunnion axes, about which the sextant is rotated to point along the star LOS. Both the star LOS and landmark LOS have a 1.8 degree field of view and a magnifying power of 28X. When looking through the sextant eyepiece, objects in the star and landmark lines of sight are superimposed. By obtaining a coincidence of a star and a landmark, the angle between the two can be measured. A cutaway of the sextant is shown in Figure 3-7.

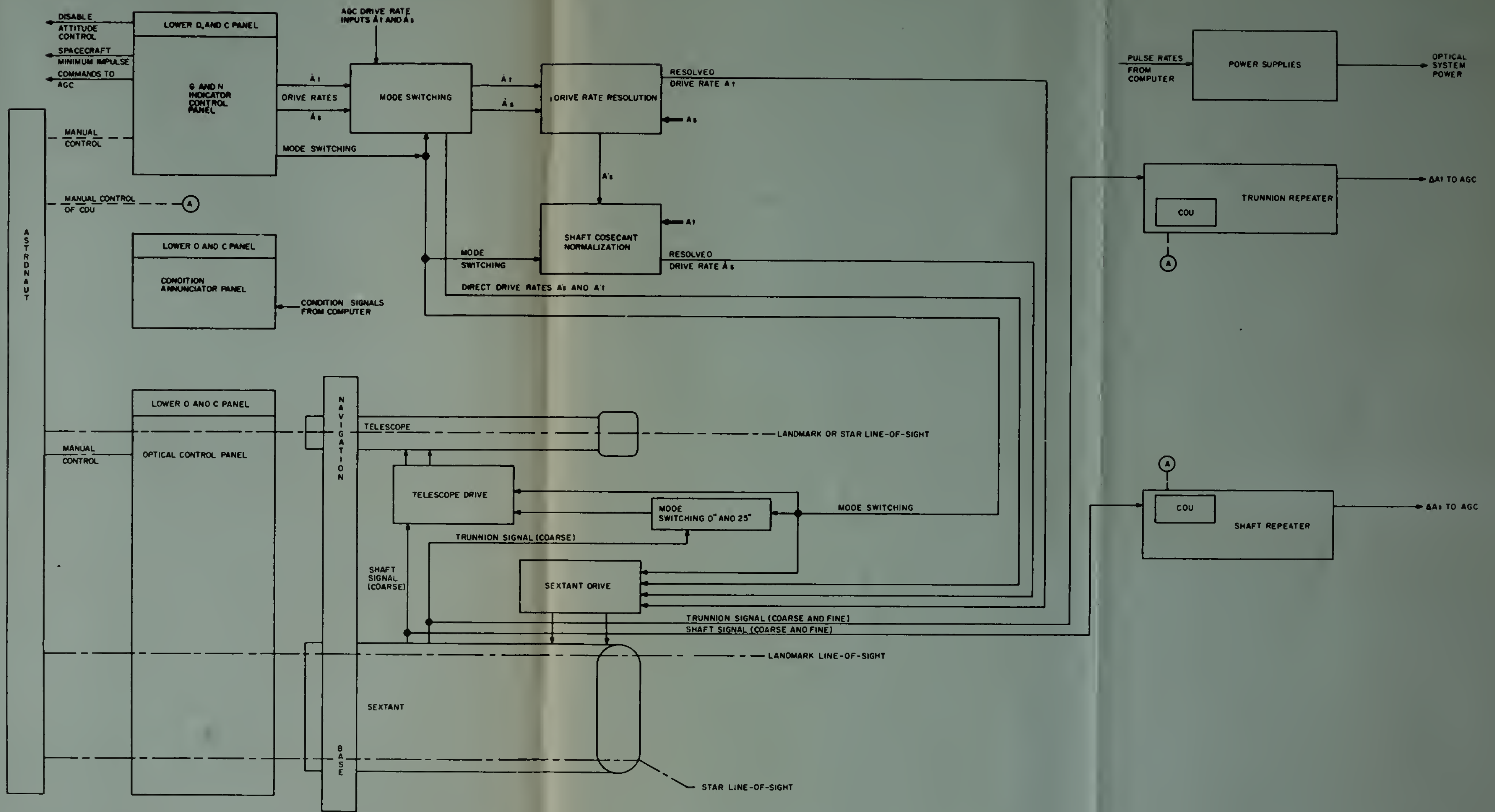


Figure 3-2. Optical Subsystem Interface

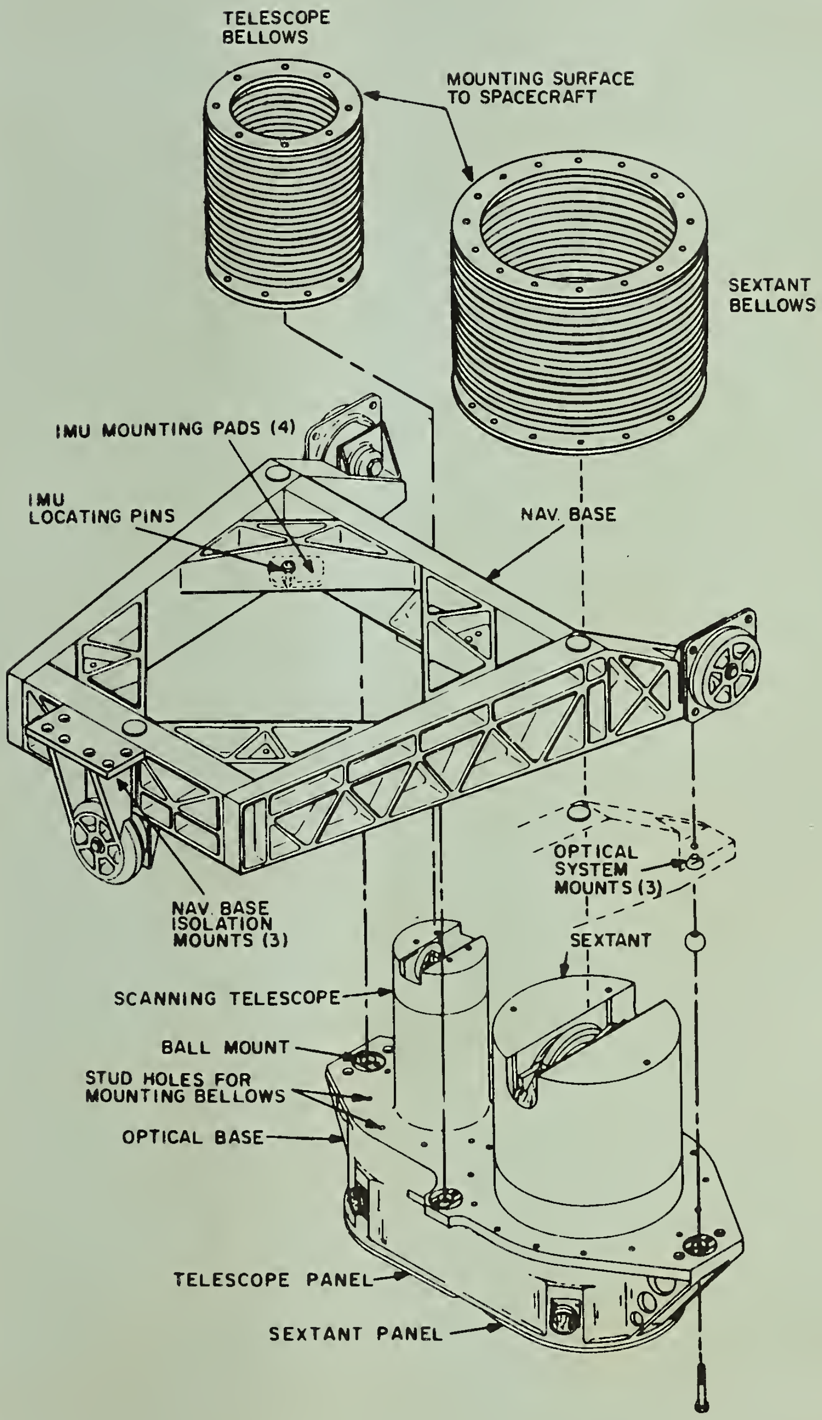


Figure 3-3. Optical Unit, Navigation Base

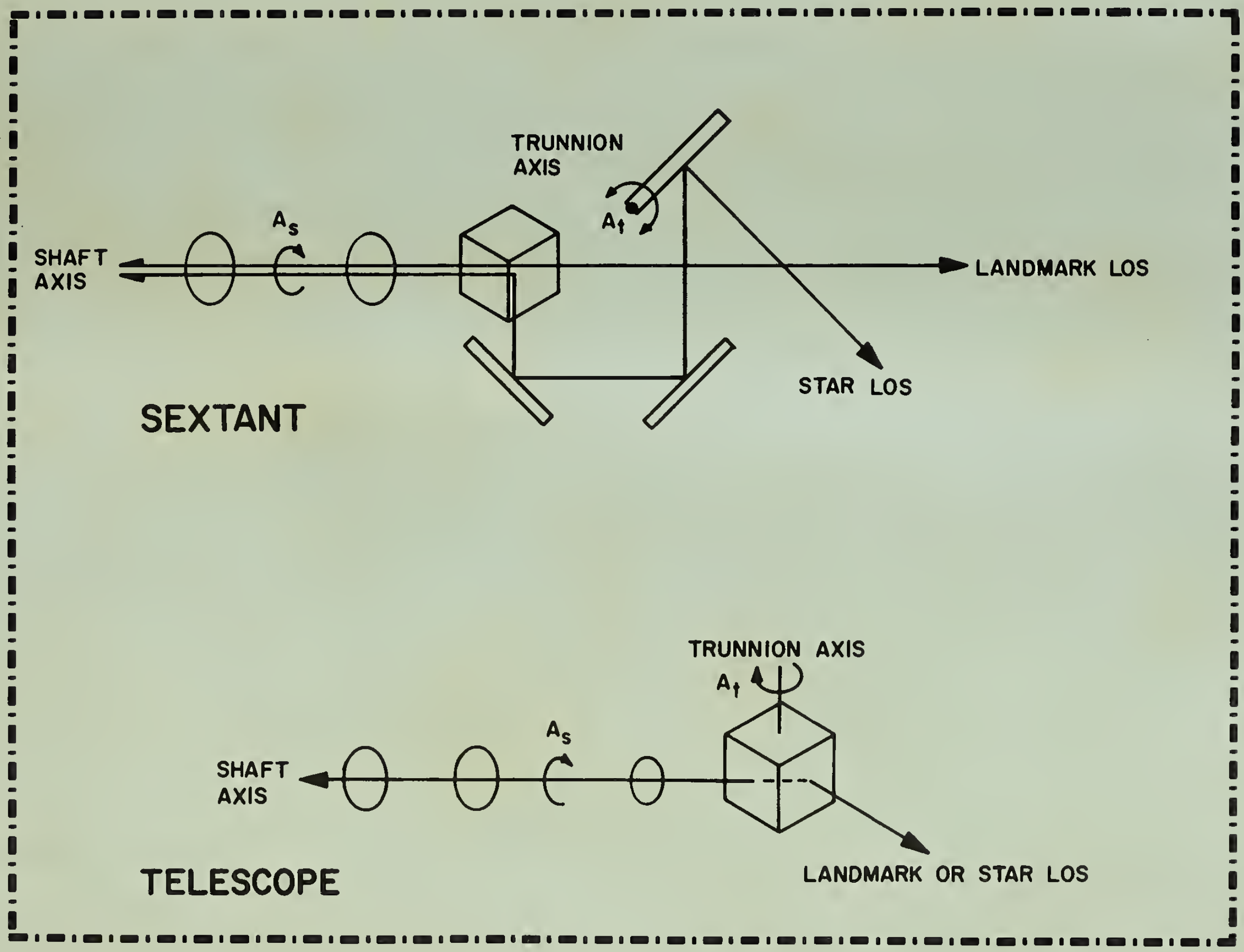


Figure 3-4. Simplified Optical Schematic

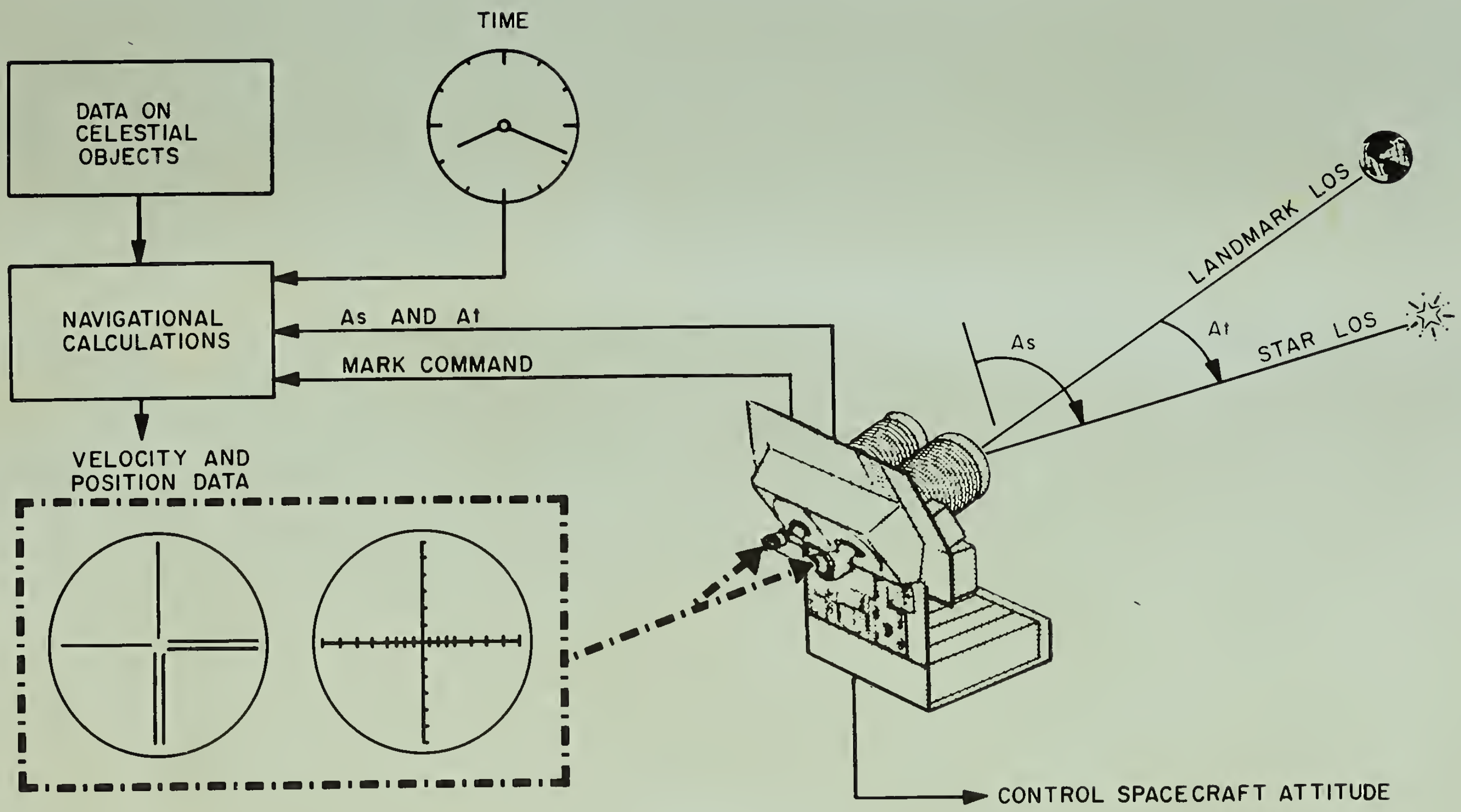


Figure 3-5. Simplified Optical Mechanization

1. Eyepiece window
2. Eyepiece prism housing assembly
3. Electrical connector
4. Relay lens assembly
5. Ball bearing (outer telescope tube assembly)
6. Outer telescope tube assembly
7. Optical base
8. Inner telescope tube assembly
9. Pechan prisms
10. Ball mount (3)
11. Ball bearing (outer telescope tube assembly)
12. Trunnion drive worm shaft
13. Dove prism and mount assembly
14. SCT head cover
15. Anti-backlash cam
16. Anti-backlash spring and cam follower
17. Objective lens assembly
18. Reticle assembly
19. Housing and lamp assembly
20. Shaft drive gear box
21. Cluster gear assembly
22. Shaft angle counter
23. Eyepiece assembly

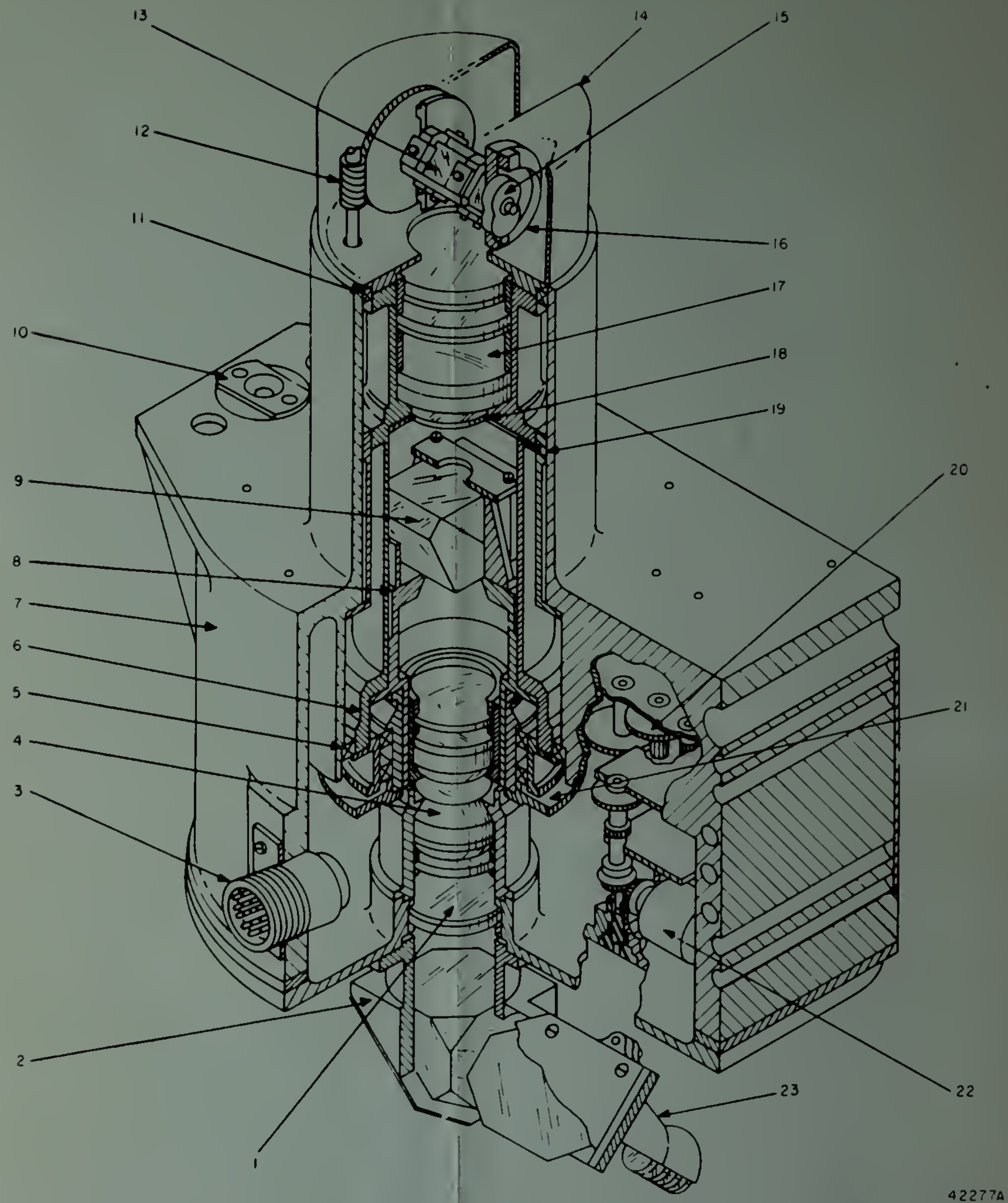


Figure 3-6. Scanning Telescope Cut-Away

1. SXT panel assembly
2. Shaft axis assembly
3. Coolant passages (not used)
4. Optical base
5. Tracker and horizon sensor power supplies (not used)
6. Ball mount (3)
7. Horizon sensor mirror (not used)
8. SXT right angle mirrors
9. Horizon sensor objective lens and filter housing (not used)
10. Trunnion resolvers
11. SXT head cover
12. Star tracker right-angle mirrors (not used)
13. Threaded rod (cover support) (2)
14. Tuning fork drive amplifiers (not used)
15. Indexing mirror and mount assembly
16. Tracker head electronics (not used)
17. Tracker tuning fork resonator (not used)
18. Star tracker photomultiplier and lens housing (not used)
19. Horizon sensor head electronics (not used)
20. Trunnion drive gear box
21. Horizon sensor photomultiplier and lens housing (not used)
22. Horizon sensor tuning fork resonator (not used)
23. SXT objective lens holder assembly
24. SXT telescope intermediate lens assembly
25. Reticle assembly
26. Shaft resolvers
27. Eyepiece window
28. Shaft drive gear box
29. Eyepiece prism assembly

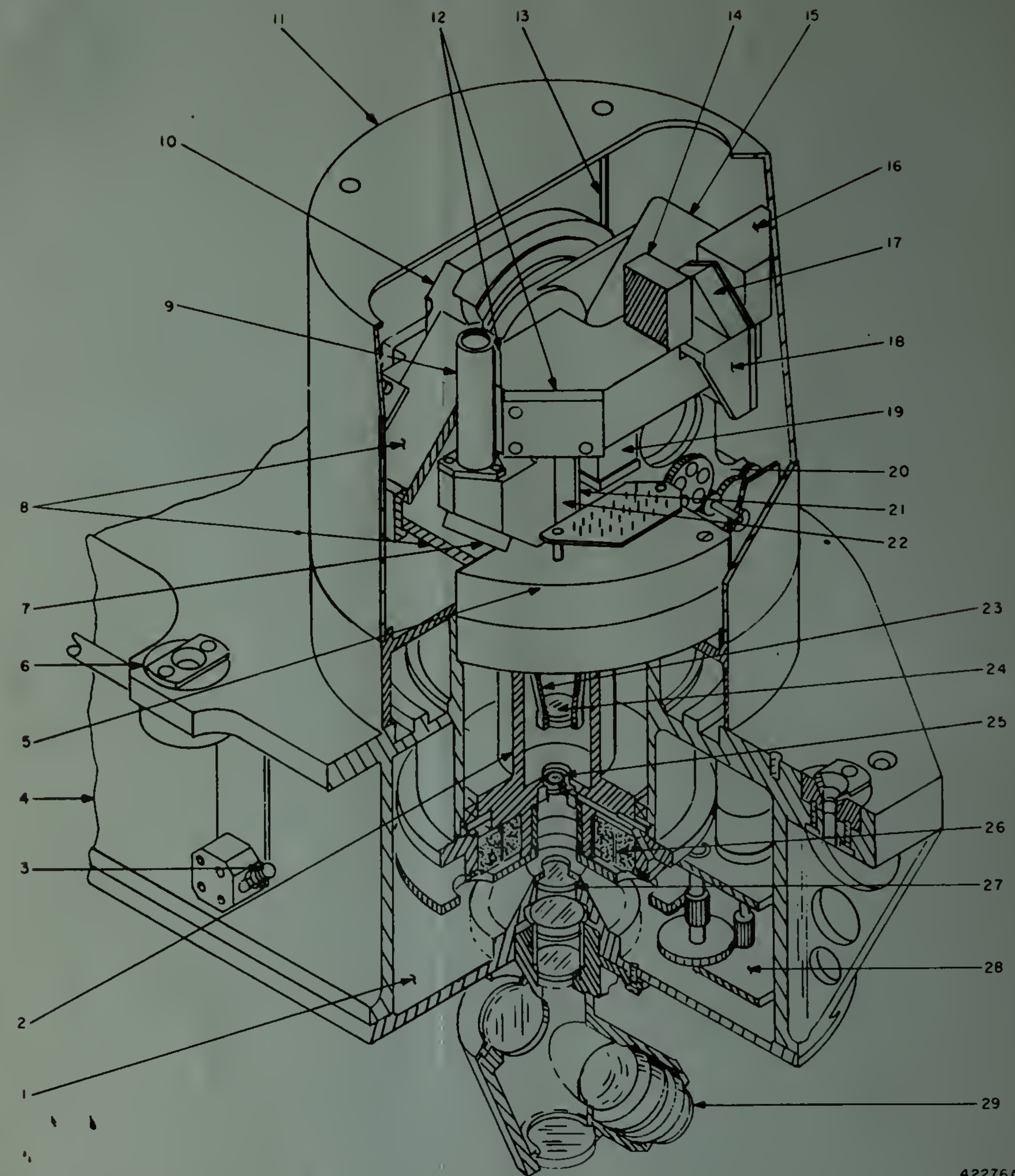


Figure 3-7. Sextant Cut-Away

3.3.4 SHAFT AND TRUNNION DRIVE. The telescope and sextant drive circuits perform similar functions; they reposition their respective shaft and trunnion axes at the commanded rate. Sextant shaft and trunnion movement can be commanded by the sextant hand controller or the computer. The telescope shaft always follows the sextant shaft. The telescope trunnion can be commanded by mode switching to follow the sextant trunnion, to 0 or 25 degrees.

3.3.5 SHAFT AND TRUNNION REPEATERS. The shaft and trunnion repeater circuits follow the sextant shaft and trunnion and display the shaft and trunnion angles. The repeater circuits include the shaft and trunnion coupling display units (CDU's) and their associated electronics. A coarse-fine resolver system is used between the sextant assembly and the shaft and trunnion CDU's. Any error signal, resulting from a difference between the CDU resolver angles and the sextant shaft or trunnion angles, drives the shaft or trunnion CDU to repeat the sextant angles. Both CDU's have a digital pickoff for transmitting changes in the shaft or trunnion angles to the AGC.

3.3.6 DRIVE RATE RESOLUTION CIRCUIT. The purposes of this circuit is to resolve the sextant hand controller drive rates so the image motion in the eyepiece (left-right for large trunnion angles and up-down) is independent of the shaft angle. Without this resolution, the direction of image movement in response to the sextant hand controller would vary and depend upon the shaft angle. The drive rates are routed through the drive rate resolution circuit by mode switching (resolved or direct) controlled from the G & N indicator control panel. The resolution is accomplished by a resolver contained in the shaft CDU.

3.3.7 SHAFT COSECANT NORMALIZATION CIRCUIT. For easier optical sightings, it is desirable that the rate of image motion (left-right or up-down) in the eyepiece be constant for a given rate input from the sextant hand controller. Since the trunnion angle affects this rate, a resolver in the trunnion repeater CDU and a cosecant amplifier are used to resolve the image motion rate. The shaft cosecant normalization circuit conditions the shaft drive rates only and is connected to the sextant hand controller by switching the optics into the resolved mode.

3.3.8 MODE SWITCHING. The mode switching is controlled from the G & N indicator control panel. The switching is performed by relay and selection switches. Table 3-1 summarizes the modes of operation.

3.3.9 DISPLAY AND CONTROL SUBSYSTEM OPERATIONS. The panels used by the optical subsystem to display and control subsystem operation and the panel functions are as follows:

1. The optical panel provides: (a) a mount for the optical eyepieces, (b) manual control of the telescope shaft and trunnion angles and (c) readouts of the telescope shaft and trunnion angles.

2. The G & N indicator control panel (see figure 2-9):

   a. Provides controls for switching optical subsystem modes.

   b. Issues mark commands to the AGC to define the time of measurement and to record shaft and trunnion angles at the time of the discrete.

   c. Issues mark rejects to the AGC to reject time and angle information which was recorded as a result of a mark command.

   d. Supplies commands to the stabilization and control system to enable attitude impulse control of the spacecraft.

   e. Controls the positioning of the optical unit by generating drive rates.

3.3.10 POWER SUPPLIES. The 28 volt 800 cps optics supply and 2.5 volt 25.6 KC encoder excitation supply, packaged in the PSA, are required to operate the optical subsystem.

The power supplies operate from 28 volt dc prime power and pulse rates from the AGC. The outputs of the power supplies are monitored for malfunction detection indications which are supplied to the AGC.

Mode or Switch	Position	Remarks
Controller mode	Direct	The optics hand controller drive rates are applied directly to the sextant drive circuits to position the sextant.
	Resolved	The optics hand controller drive rates are resolved by the drive rate resolution and shaft cosecant normalization circuits before positioning the sextant.
Optics mode	Manual	Normal operating position where the sextant and telescope are positioned by the optics hand controller.
	Zero	Reference signal is switched into the integrating loop which drives the loops to a zeroed position.
	Computer	The computer positions the sextant and telescope as in manual direct.
Controller speed	Hi Med Low	Three-position attenuator varies the sensitivity of the optics hand controller.
Slave telescope	Star Line	Telescope trunnion slaved to the sextant trunnion.
	0°	Drives telescope trunnion to a zero setting independent of the trunnion CDU.
	25°	Drives telescope trunnion to a 25° setting independent of the trunnion CDU.
Mark		Signal to AGC indicating instant of measurement.
Mark reject		Rejects time and angles recorded as a result of a mark command.
Tracker power (not used)		Provides power for the operation of the star tracker and horizon photometer.
Attitude enable		Disables the stabilization and control system attitude control capability prior to using the minimum impulse controller.
Minimum impulse controller		Generates roll, pitch and yaw signals for spacecraft rate control.
Track button (not used)		Applies the star tracker trunnion error signal to the sextant trunnion drive circuit directly. Applies the star tracker shaft error signal to the sextant shaft cosecant normalization circuit. The telescope can be driven in trunnion by optics hand controller.

Table 3-1. Optical Subsystem Switching

3.4 OSS EQUIPMENT MODES

The OSS has four basic modes of operation: (1) zero optics, (2) manual, (3) computer and (4) star tracker. These modes are briefly discussed in the following paragraphs.

3.4.1 ZERO OPTICS MODE.

The zero optics mode can be initiated from either the G & N indicator control panel by the astronaut or automatically by the computer (see Figure 3-8).

During zero optics, the optical unit and the CDU's are driven to a zero reference point and the computer clears the optical registers. The reference point is defined as the orientation which causes the telescope and sextant lines of sight to be parallel to the Z navigation base axis, with the trunnion axes parallel to the Y navigation base axis. The CDU's are driven to their zero degree position.

This mode is mechanized by connecting the sextant coarse-fine error signals back to the sextant drive motors which then cause the sextant to drive to the electrical zero point. The CDU's and telescope are slaved to the sextant. The CDU's utilize the sextant coarse-fine error signals and the telescope utilizes only the sextant coarse error signals. When zero optics is completed, the computer clears the registers associated with the optical subsystem.

3.4.2 MANUAL MODE.

The manual mode of operation can be divided into two distinct submodes, manual direct and manual resolved. These submodes are discussed below.

3.4.2.1 Manual Direct. The manual direct mode is initiated from the G & N indicator control panel by the astronaut. The astronaut then controls the positioning of the optics and CDU's directly from the optical hand controller (see Figure 2-9). During manual direct operations, the error signals from the optics hand controller are applied directly to the sextant drive loop to position the optics and CDU's. This mode of operation is primarily used for coarse acquisition of the stars and landmarks in the scanning telescope. An up or down movement of the optical hand controller results in a trunnion movement or apparent image motion parallel to the "R" line in the reticle pattern. A left or right movement of the optics hand controller results in a rotation of the reticle pattern about the shaft axis (see Figure 3-9).

This mode is mechanized by connecting the output errors of the optical hand controller directly to the sextant shaft and trunnion drive loops. The sextant resolvers develop coarse-fine error signals which are applied to the shaft and trunnion CDU resolvers. The CDU resolvers provide error signals whenever there is an angle difference between the sextant and the CDU's. These error signals are applied to the CDU drive loop, which causes the CDU's to follow the sextant. The scanning telescope uses the sextant coarse error signal to cause the telescope shaft to follow the sextant shaft.

The telescope trunnion drive signal is applied to the telescope resolver via the slave telescope moding circuit. The slave telescope switch determines which error signal is applied to the telescope trunnion resolver. If the slave telescope switch is in the SLOS position, the sextant coarse resolver error signal is applied to the telescope resolver. The resulting error signal is then applied to the telescope trunnion drive loop, thereby slaving the telescope trunnion to the sextant. If the slave telescope switch is in the LLOS position, a 28 volt 800 cps signal, instead of the sextant error signal, is applied to the telescope trunnion resolver. This constant signal drives the telescope trunnion to the zero reference position (trunnion angle to zero degrees) and holds it slaved to 0°.

ZERO OPTICS MODE

Description of Signals:

1. Mode selection commands.
2. Output of the sextant trunnion resolver, which is proportional to the sextant trunnion angle. This signal drives the sextant trunnion to zero degrees and is applied to the trunnion CDU and the telescope trunnion resolvers.
3. Output of the trunnion CDU resolver, which is used to drive the trunnion CDU to the sextant trunnion angle.
4. Trunnion CDU encoder output, which indicates changes in the trunnion CDU position.
5. Telescope trunnion resolver output, which is used to drive the telescope in trunnion to the sextant trunnion angle.
6. Output of the sextant shaft resolver, which is proportional to the sextant shaft angle. This signal is used to drive the sextant shaft to zero degrees and is applied to the shaft CDU resolver and the telescope shaft resolver.
7. Output of the shaft CDU resolver, which is used to drive the shaft CDU to the sextant shaft angle.
8. Shaft CDU encoder output, which indicates changes in the shaft CDU position.
9. Telescope shaft resolver output, which is used to drive the telescope in shaft to the sextant shaft angle.

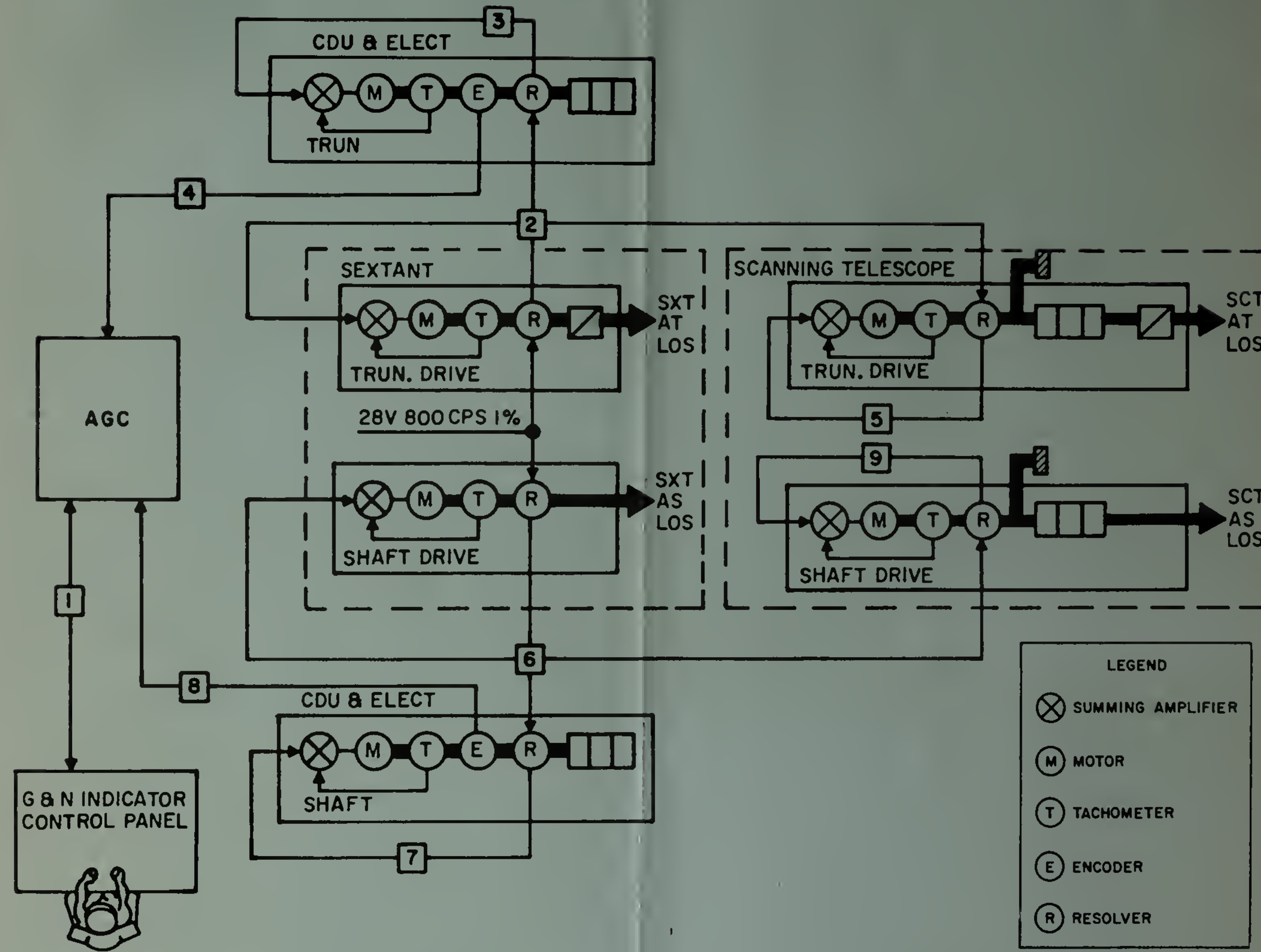


Figure 3-8. Zero Optics Mode

MANUAL DIRECT MODE

Description of Signals:

1. Optics hand controller output which is used to position the sextant in trunnion.
2. Output of the sextant trunnion resolver which is proportional to the sextant trunnion angle.
3. Output of the trunnion CDU resolver, which is used to drive the CDU to the sextant trunnion angle.
4. Trunnion CDU encoder output which indicates changes in the trunnion CDU position to the AGC.
5. Output of the slave telescope moding circuitry used to:
    a. Slave the telescope trunnion to zero degrees.
    b. Slave the telescope trunnion to 25 degrees.
    c. Slave the telescope trunnion to the sextant trunnion.
6. Output of the telescope trunnion resolver which is used to drive the telescope to the commanded position.
7. Optics hand controller output which is used to position the sextant in shaft.
8. Output of the sextant shaft resolver which is proportional to the sextant shaft angle.
9. Output of the shaft CDU resolver which is used to drive the shaft CDU to the sextant shaft angle.
10. Shaft CDU encoder output which indicates changes in the shaft CDU position to the AGC.
11. Output of the telescope shaft resolver used to drive the telescope to the sextant shaft angle.

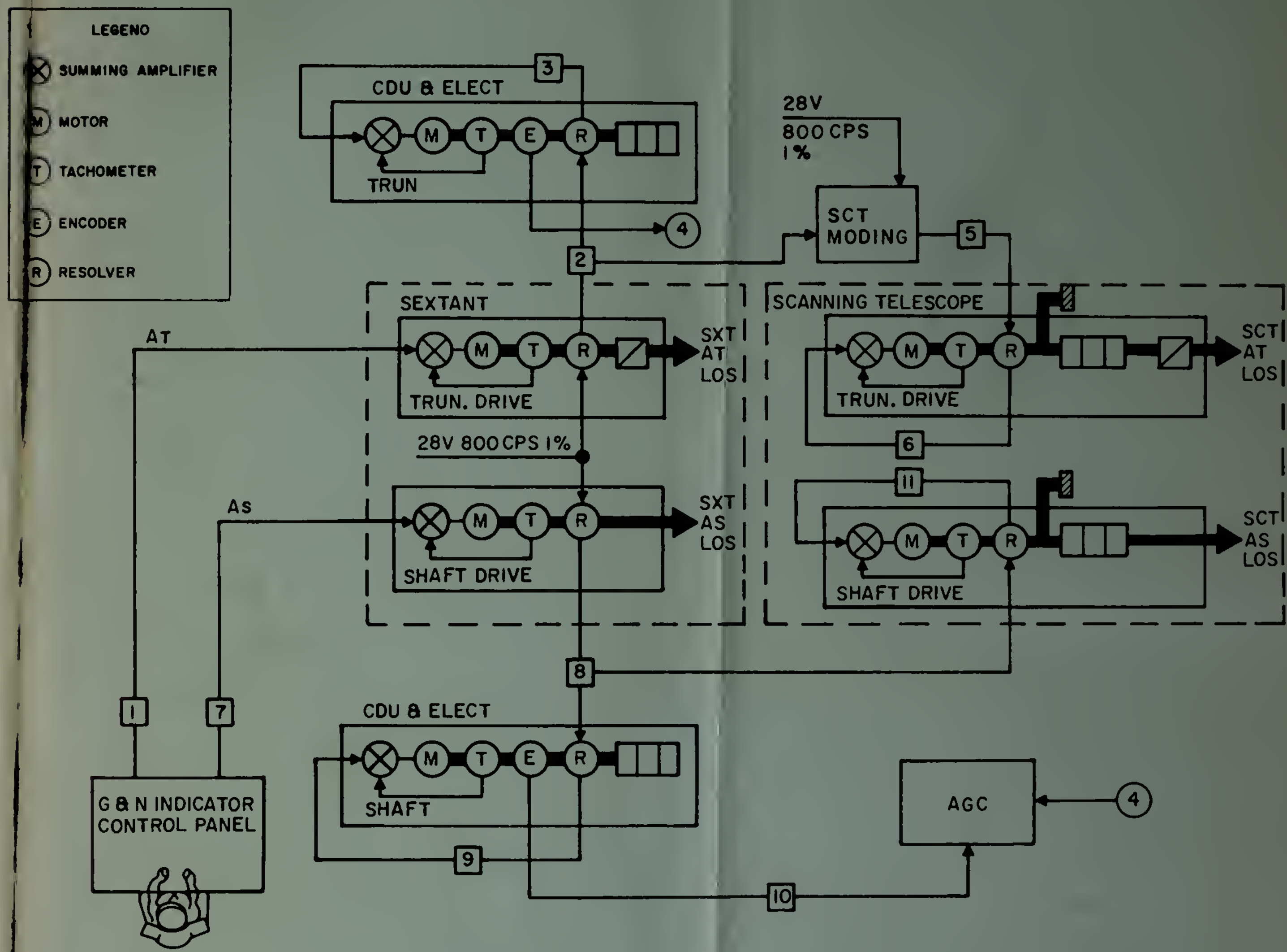


Figure 3-9. Manual Direct Mode

3.4.2.2 Manual Resolved. The manual resolved mode is initiated from the G & N indicator control panel by the astronaut. The astronaut then controls the positioning of the optics and CDU's from the optics hand controller through the drive rate resolution and shaft cosecant normalization circuits (see figure 3-10).

The manual resolved mode converts the optics hand controller A_t and A_s signals from polar to rectangular coordinates and makes the shaft drive signal dependent on trunnion angle. An up or down movement of the hand controller causes an up or down apparent image motion in the reticle. A left or right movement of the hand controller causes a left or right apparent image motion in the reticle. This makes the apparent image motion independent of shaft rotation. The shaft cosecant normalization circuit reduces the shaft drive rate when the trunnion angle is large so that the apparent image rate is constant for all trunnion angles. During the manual resolved mode, the outputs of the optics hand controller are routed to a shaft CDU resolver for drive rate resolution. This circuit converts apparent image motion from polar to rectangular coordinates. The SXT trunnion drive signal is applied to the sextant trunnion drive loop. The trunnion CDU and the telescope trunnion follow as in the manual direct mode. The SXT shaft drive signal is routed from the shaft CDU resolver to the shaft cosecant normalization circuit, which consists of a negative feedback amplifier and a trunnion CDU resolver. The trunnion CDU resolver provides the negative feedback for the amplifier, which then provides a shaft drive rate, which is constant for all trunnion angles. The shaft CDU and the telescope shaft then follow the sextant as in the manual direct mode.

3.4.3 COMPUTER MODE. The computer mode is initiated from the G & N indicator control panel by the astronaut. The computer then controls and drives the OSS loops. The computer can initiate: (1) zero optics, and (2) computer torquing. (See figure 3-11.) During the computer mode, the AGC routes its torquing pulse trains to the digital to analog converter (DAC) which converts the digital pulses into analog signals that drive the sextant. As the sextant is driven, the CDU's and telescope follow as in the manual direct mode. As the CDU's follow, the CDU encoders convert shaft rotation into digital pulses, which are sent to the DAC and the AGC. The encoder pulses to the DAC reduce the DAC output until it is reduced to zero. The encoder pulses to the AGC are accumulated in the optical registers and indicate optical angles.

3.5 SUMMARY

The OSS is used to determine spacecraft position and attitude by use of the optical unit. The optical unit consists of a telescope and sextant. The telescope is a wide angle, low power unit used for coarse acquisition of celestial bodies. The sextant is a dual line of sight, narrow field of view, high power of magnification unit used to finely acquire celestial bodies. The OSS provides the CSS with shaft and trunnion angles from which the AGC calculates spacecraft position and orientation.

The OSS equipment consists of:

a. Navigation Base

b. Optical Unit

c. Coupling Display Units (two)

d. Power and Servo Assembly

e. G & N Indicator Control Panel

f. Optical Panel

MANUAL RESOLVED MODE

Description of Signals:

1. Optics hand controller shaft and trunnion output.
2. Resolved sextant trunnion drive signal. (Polar to rectangular coordinates.) Used to position the sextant in trunnion.
3. Output of the sextant trunnion resolver which is proportional to the sextant trunnion angle.
4. Output of the trunnion CDU resolver which is used to drive the trunnion CDU to the sextant trunnion angle.
5. Trunnion CDU encoder output which indicates changes in the trunnion CDU position to the AGC.
6. Telescope trunnion resolver output which is used to drive the telescope trunnion to the sextant trunnion position.
7. Resolved sextant shaft drive signal. (Polar to rectangular coordinates.)
8. Resolved sextant shaft drive signal which repositions the sextant in shaft at a rate independent of trunnion angle.
9. Output of the sextant shaft resolver which is proportional to the sextant shaft angle.
10. Output of the shaft CDU resolver which is used to drive the shaft CDU to the sextant shaft angle.
11. Shaft CDU encoder output which indicates changes in the shaft CDU position to the AGC.
12. Telescope shaft resolver output which is used to drive the telescope shaft to the sextant shaft position.

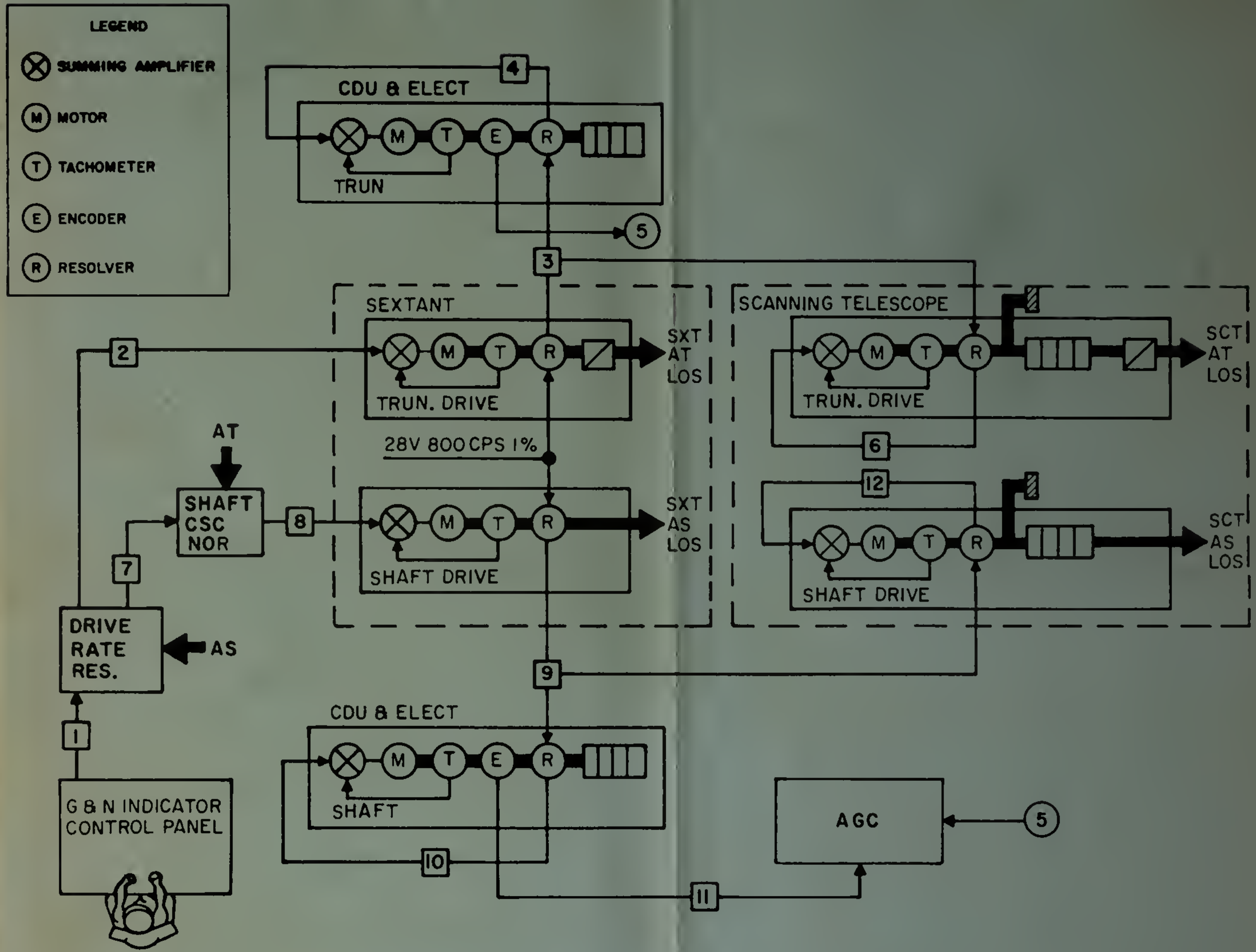


Figure 3-10. Manual Resolved Mode

COMPUTER MODE

Description of Signals:

1. Computer mode selection command.
2. AGC trunnion drive signal which positions the sextant in trunnion.
3. Output of the sextant trunnion resolver which is proportional to the sextant trunnion angle.
4. Output of the trunnion CDU resolver which is used to drive the trunnion CDU to the sextant trunnion angle.
5. Trunnion CDU encoder output which indicates changes in the trunnion CDU position to the AGC.
6. Telescope trunnion resolver output which is used to drive the telescope to the sextant trunnion angle.
7. AGC shaft drive signal which positions the sextant in shaft.
8. Output of the sextant shaft resolver which is proportional to the sextant trunnion angle.
9. Output of the shaft CDU resolver which is used to drive the shaft CDU to the sextant shaft angle.
10. Shaft CDU encoder output which indicates changes in the shaft CDU position to the AGC.
11. Telescope shaft resolver output which is used to drive the telescope to the sextant shaft angle.

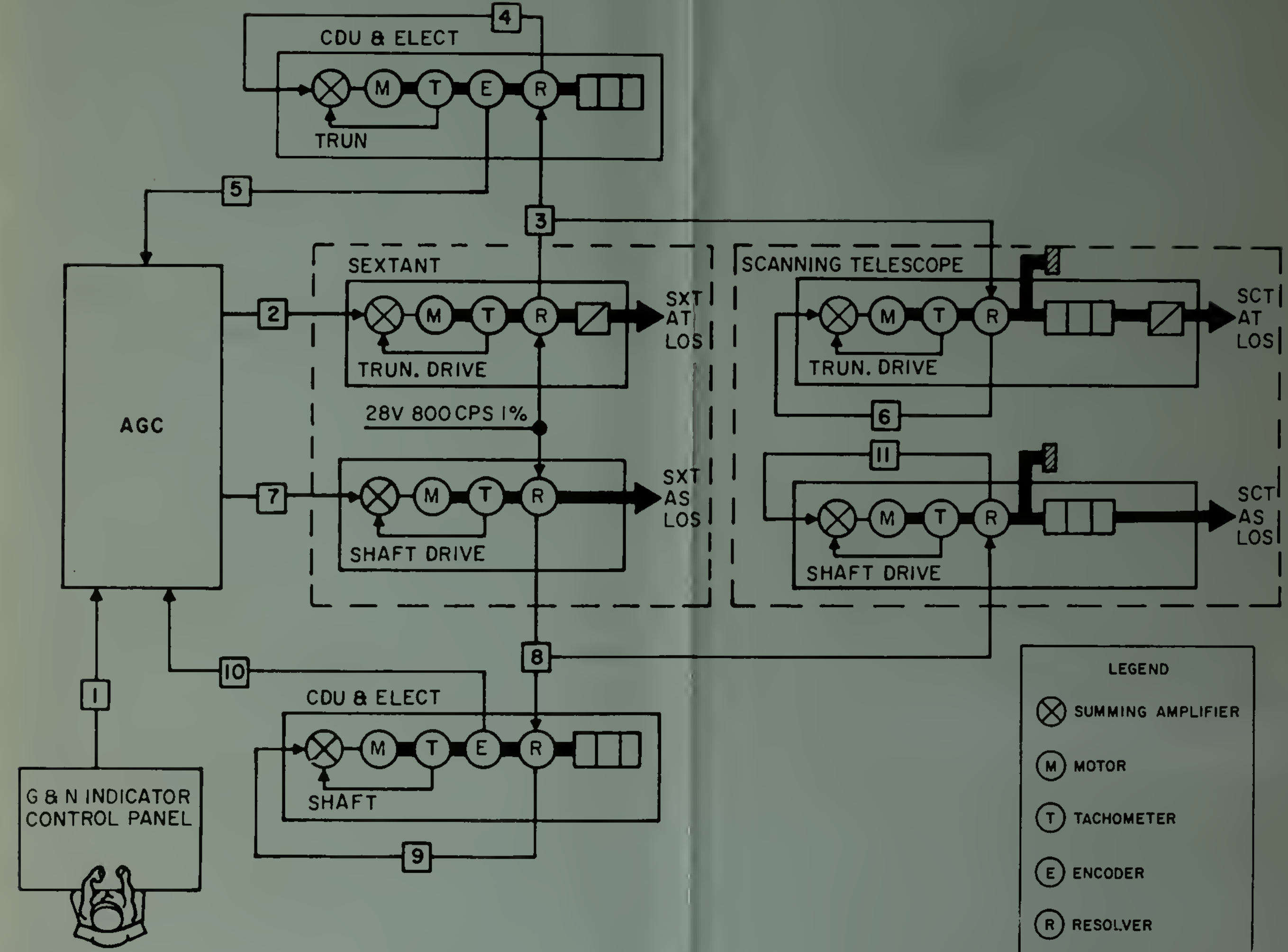


Figure 3-11. Computer Mode

The OSS equipment modes and their basic functions are:

a. ZERO OPTICS - The sextant, telescope and CDU's are driven to a zero reference point.

b. MANUAL MODE - The sextant, telescope and CDU's are positioned manually by the optical hand controller by the astronaut.

c. COMPUTER MODE - The sextant, telescope and CDU's are positioned by the AGC.

REVIEW QUESTIONS FOR SECTION III

T F 1. Two basic optical subsystem functions are navigation and IMU alignment sightings.

T F 2. The sextant is a dual line of sight optical instrument.

T F 3. The sextant is used for coarse acquisition of the celestial bodies.

T F 4. The telescope has a large field of view.

T F 5. The telescope is used for coarse acquisition of celestial bodies.

T F 6. The telescope is a dual line of sight optical instrument.

T F 7. The optical CDU's are used to drive the sextant and telescope.

8. What is the function of the zero optics mode?

9. During the manual mode of operation, the optical hand controller develops the error signal to position the optics. This error signal drives what unit?

10. In the manual resolved mode of operation, the optical hand controller error signals are conditioned prior to driving the optics. What conditioning takes place?

SECTION IV

COMPUTER SUBSYSTEM

INTRODUCTION

This section of the Study Guide briefly describes the CSS equipment. The CSS is divided into functional blocks and discussed. A brief description of the CSS functional operations and programing is also presented in this section.

4.1 CSS PURPOSE

The computer subsystem is the control and computational center of the G & N system. It performs the following functions:

a. Solves the guidance and navigation problems for all mission phases.

b. Provides control information to the G & N system, as well as other spacecraft systems.

c. Displays pertinent information to the astronaut and the ground when requested.

d. Provides a means by which the astronaut or ground control can directly communicate with the G & N system.

e. Monitors its own operation and certain other spacecraft system operations.

4.2 CSS EQUIPMENT

The CSS consists of the Apollo guidance computer (AGC) and two display and keyboards (DSKY's) (see Figure 4-1). The AGC is located in the lower center of the lower display and control panel below the power and servo assembly. One DSKY is located on the lower display and control panel and is called the navigation panel DSKY. The other DSKY is located on the main display and control panel and is called the main panel DSKY.

4.2.1 APOLLO GUIDANCE COMPUTER (AGC). The AGC is a core memory, digital computer with two types of memory: fixed and erasable. The fixed memory permanently stores navigation tables, trajectory parameters, programs and constants. The erasable memory stores intermediate information.

The AGC processes data and issues discrete control signals, both for the G & N system and the other spacecraft systems. It is a control computer with many of the features of a general purpose computer. As a control computer, the AGC aligns the stable platform of the inertial measurement unit (IMU) in the inertial subsystem, positions the optical unit in the optical subsystem and issues control commands to the spacecraft. As a general purpose computer, the AGC solves G & N problems required for the spacecraft mission. In addition, the AGC monitors the operation of the G & N system.

The AGC stores data pertinent to the flight profile that the spacecraft must assume in order to complete its mission. This data, consisting of position, velocity and trajectory information, is used by the AGC to solve the flight and steering equations during orbital injections and mid-course velocity corrections. The results determine the required magnitude and direction of thrust required. Corrections to be made are established by the AGC. The spacecraft engines are turned on at the correct time, and steering signals are controlled by the AGC to re-orient the spacecraft to a new trajectory, if required. The inertial subsystem senses acceleration and supplies velocity changes to the AGC for calculating the total velocity. Drive signals are

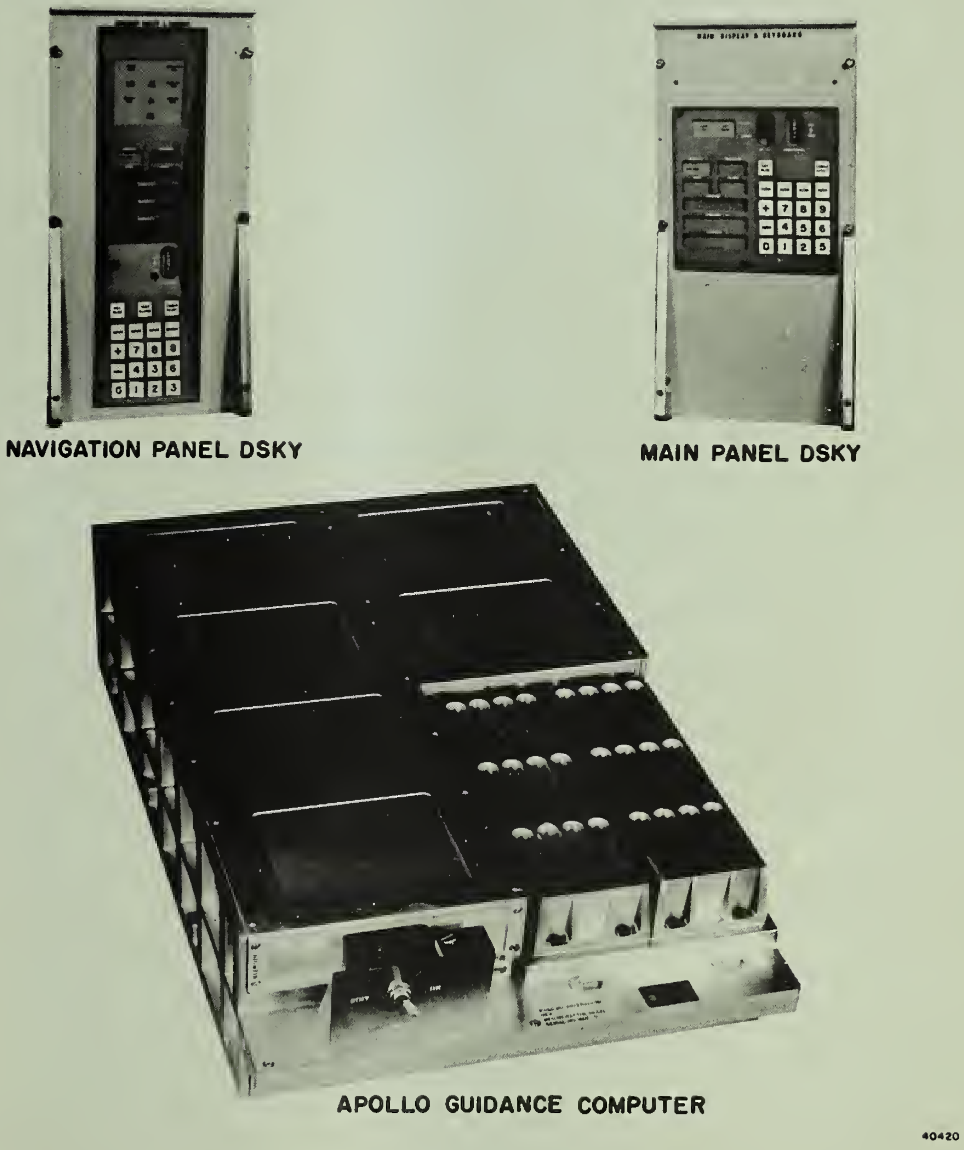


Figure 4-1. Computer Subsystem Equipment

supplied from the AGC to coupling display units (CDU's) and stabilization gyros in the inertial subsystem to align the gimbal angles in the IMU. Drive signals are also supplied to the CDU's to provide steering capabilities for the spacecraft. CDU position signals are fed to the AGC to indicate changes in gimbal angles, which are used by the AGC to keep cognizant of the gimbal positions. The AGC receives mode indications and angular information from the optical subsystem during optical sightings. This information is used by the AGC to calculate present position and orientation and is used to refine trajectory information. Optical subsystem components can also be positioned by drive signals supplied from the AGC.

4.2.2 NAVIGATION DSKY. The navigation DSKY is located on the lower display and control panel and provides a two-way communications link between the astronaut and the AGC (see Figure 4-2). Through this communications link, the following functions can be performed:

a. Loading of data into the AGC.

b. Display of data from the AGC and data loaded into the AGC.

c. Monitoring of data from the AGC.

d. Display of the AGC modes of operation.

e. System control by the initiation of subsystem and system testing and control of the system's major modes of operation.

f. Requests by the AGC to the system operator to perform actions.

The navigation DSKY consists of a keyboard, display panel, condition indicators, a power supply and a relay package (see Figure 4-2). The keyboard provides the astronaut with the capability of inserting data into the AGC and initiating AGC operations. Through the keyboard, the astronaut can also control the ISS moding and some OSS moding. The DSKY display panel provides a visual indication of data being loaded into the AGC, the AGC activity and AGC program. The display panel also provides the AGC with a means of displaying or requesting data. The condition indicators display specific AGC failures.

4.2.3 MAIN PANEL DSKY. The main panel DSKY is located on the main display and control panel and provides a two-way communications link between the astronaut and the AGC, while the astronauts are at their couches. The main panel DSKY (see Figure 4-3) operates in parallel with the navigation DSKY.

The main panel DSKY is functionally the same as the navigation DSKY, with the following exceptions:

a. There are only two condition indicators on the main DSKY; COMPUTER FAIL, which is a gross AGC failure indication and KEY RELEASE, which is an indication that the AGC wants to use the DSKY displays.

b. There is no test alarm pushbutton on the main DSKY.

c. A telemetry switch (UP TEL) enables the astronaut to block or accept the UPLINK telemetry data.

d. A telemetry interface to provide ground operations with the COMPUTER FAIL indication.

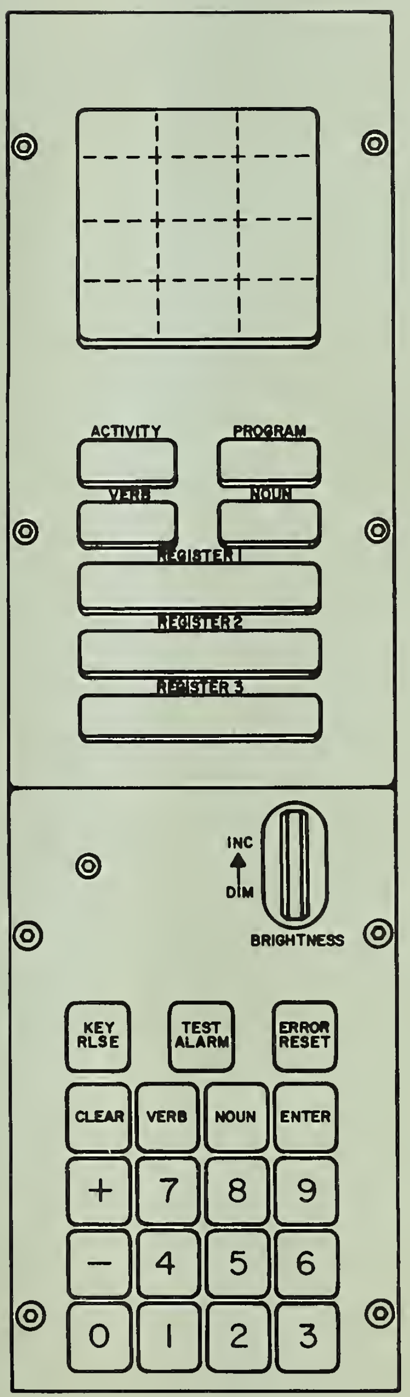


Figure 4-2. Navigation Panel Display and Keyboard

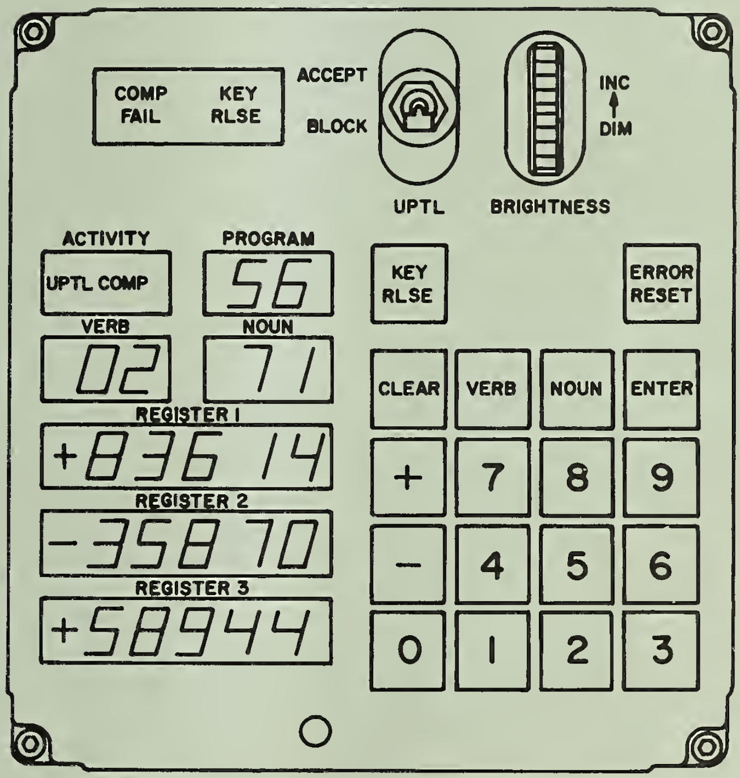


Figure 4-3. Main Panel Display and Keyboard

4.3 COMPUTER SUBSYSTEM FUNCTIONAL BLOCKS

The CSS has been divided into 17 functional blocks for the purpose of explanation. These functional blocks and their interfaces are illustrated in Figure 4-4. The operation and interrelationship of these blocks are discussed in the following paragraphs.

4.3.1 PROCESSING CONTROL. The processing control block is basically the central processing element of the CSS. It consists of logic circuitry and storage capacity, which contains the programs and information necessary to enable the AGC to fulfill its functions of control and data processing.

The processing control block:

a. Controls the computer's sequence of operation.

b. Processes all the inputs according to their priority.

c. Solves the G & N problems associated with the Apollo mission.

d. Provides output signals to control the modes and position the ISS and OSS.

e. Provides output signals to control other spacecraft systems.

f. Provides G & N data outputs to the communications system.

g. Monitors the G & N system for failures.

4.3.2 TIMER. The timer functional block provides the necessary synchronization or timing pulses to insure a logical flow of data from one area to another within the AGC and provides synchronization or timing pulses to the other G & N subsystems for power supply frequency stabilization and other control functions. Other spacecraft systems receive timing signals for control and synchronization purposes. The spacecraft central timing equipment (CTE) is synchronized to the AGC timer.

4.3.3 AGC POWER SUPPLIES. There are three power supplies within the AGC. They receive prime +28 vdc power from the electrical power system and develop +13 vdc and +3 vdc power which is used within the AGC for logic power. The +13 vdc power supply also provides input power to the main and navigation panel DSKY power supplies. The two +3 vdc power supplies, +3A and +3B, provide for the STANDBY-OPERATED mode of operation of the AGC.

4.3.4 MODE CONTROL. The CSS has two modes of operation: standby and operate. The control switch is a two-position toggle switch located on the front panel of the AGC. When the mode control switch is in the STANDBY position, only the computer timing block is operating powered by the +3B, +3 vdc power supply. During CSS standby, the AGC maintains real time and supplies timing pulses to the S/C systems. When the mode control switch is in the OPERATE position, the computer is operative. When in the operate mode, all three AGC power supplies are operative.

4.3.5 INPUT INTERFACE. The input interface functional block receives signals from the G & N system and the other spacecraft systems. These signals are then conditioned and isolated by the input interface, prior to being routed into the AGC logic circuitry.

4.3.6 OUTPUT INTERFACE. The output interface functional block conditions and isolates the AGC signals, prior to routing them to the appropriate CSS block, G & N subsystem, or spacecraft system.

4.3.7 AGC ALARM CIRCUITS. The AGC alarm circuits functional block monitors the operation of the AGC. If an AGC failure is discovered, a gross computer failure signal is routed to the main panel DSKY and the specific AGC failure is routed to the navigation DSKY for display. These failures are then displayed on the DSKY's. A computer power failure can be displayed on the main and navigation panel condition indicators.

4.3.8 NAVIGATION PANEL DSKY KEYBOARD. (See figure 4-2) The navigation panel DSKY keyboard is used to manually insert or call up AGC data. The keyboard consists of 10 numerical pushbuttons (0-9), two algebraic sign pushbuttons (+ and -) and seven instruction pushbuttons (enter, clear, verb, noun, test alarm, error reset, and key release). All the pushbuttons, except the TEST ALARM pushbutton, have five bit codes associated with them and convey information to the AGC. The TEST ALARM pushbutton is hard-wired into the input interface block. These controls and their functions are listed in Table 4-1.

Table 4-1 - Navigation DSKY Controls

Control	Function
0 - 9 keys	Used to enter data, address codes and action request codes into the AGC.
Verb key	Conditions the AGC to interpret the following two numerical characters as an action request code and causes the verb display to be blanked.
Noun key	Conditions the AGC to interpret the following two numerical characters as an address code and causes the noun display to be blanked.
Enter key	Informs the AGC that the assembled data is complete and to execute the requested function.
(+) and (-) keys	Informs the AGC that the following data is decimal and indicates the sign of the data.
Clear key	Clears data contained in the data registers. Depressing the key clears whichever display register that is currently being used. Successive CLEARS clear the upper display registers.
Error reset key	Extinguishes the failure lights that are controlled by the AGC.
Test alarm key	Tests the parity, counter, rupt, and TC trap failure lights on the DSKY condition indicator panel to insure that they are operating.
Key release key	Releases the DSKY displays initiated by keyboard action so that information supplied by the AGC program action may be displayed.
Brightness	Varies the intensity of the display indicators.

4.3.9 NAVIGATION PANEL DSKY CONDITION AND INFORMATION DISPLAY. (See figure 4-2.) The information display functional block provides the astronaut with a visual readout of information being inserted into or extracted from the AGC and AGC failure indications. The DSKY information display consists of three five bit registers (R_1, R_2 and R_3), a verb display, a noun display, an AGC activity indicator, a program display, and nine AGC condition displays. The three registers display the actual data extracted or inserted. The verb and noun displays display the verb and noun codes inserted into the AGC or used by the AGC to "talk" to the astronaut. The activity indicator indicates when the AGC is receiving UPLINK telemetry transmission with the telemetry activity indication. The fact that the AGC is processing a program is indicated by this computer activity indicator. The program display indicates the major program in process. The condition indicators display nine AGC conditions. Each indicator is labeled with the condition it represents and is illuminated if that condition occurs. All computer alarm conditions are telemetered to the ground stations. The alarm indications and their functions are described in Table 4-2.

Table 4-2 - AGC Alarm Lights (Navigation DSKY)

Alarm	Function
A. Program word errors	
Program alarm	Indicates that the AGC program has detected an erroneous condition.
Parity fail	Indicates that a number stored in the memory is read out incorrectly.
Check fail	Indicates an illegal DSKY operation (usually caused by an operator error).
TL fail	Indicates: 1. Downlink word rate too high or too low. 2. Uplink bit rate too high or incorrect transmission of data.
B. Logic failures	
Rupt lock	Indicates that the AGC has either been in an interrupted state too long or that an interrupt has not occurred within a specified time.
TC trap	Indicates that the AGC is either "hung-up" in an endless loop of instructions or has not transferred control within a specified time.
Scaler fail	Indicates a failure of the AGC timing circuitry.
Counter fail	Indicates a failure in the normal sequence of input pulse counting (either the interrupt or the circuitry itself).
Although not an alarm, the alarm matrix also contains:	
Key release	Indicates than an internal program wishes to display information on the DSKY, but has found the keyboard in use by the operator.

4.3.10 NAVIGATION PANEL DSKY MODE AND CONDITION INDICATOR CONTROL. The mode and condition indicator control functional block provides the switching necessary to initiate G & N mode selection and control of the DSKY's and main and navigation panel condition indicator display panels. This block receives its control signals from the AGC. The AGC monitors the input interface signals for changes in condition and provides the necessary signals to the mode and condition indicator control block.

4.3.11 NAVIGATION PANEL DSKY POWER SUPPLY. The DSKY power supply receives +28 vdc, +13 vdc and an 800 cps sync signal from the AGC. The power supply develops 275 v, 800 cps power. The power supply output is used to provide power for the DSKY electroluminescent display panels.

4.3.12 MAIN PANEL DSKY KEYBOARD. The main panel DSKY keyboard provides the astronaut with a communications link with the AGC while at his couch. The main DSKY keyboard operates in parallel with the navigation DSKY keyboard. The keyboards are identical with one exception; the main DSKY keyboard does not have a test alarm pushbutton.

4.3.13 MAIN PANEL DSKY CONDITION AND INFORMATION DISPLAYS. The main panel DSKY condition and information display functional block provides the astronaut with a visual readout of information being inserted into or extracted from the AGC, and a gross AGC failure indication. The only difference between the main and navigation panel DSKY condition and information display blocks is that the main panel DSKY has only two condition indicators. One condition indicator is the COMPUTER FAIL indicator which lights whenever one of the navigation DSKY condition indicators lights with the exception of telemetry alarm and key release. The navigation DSKY condition indicators indicate a specific failure, while the main panel DSKY condition indicator indicates only a gross AGC failure. The other condition indicator of the main panel DSKY is KEY RELEASE and indicates that the AGC is requesting the astronaut to release the DSKY for AGC use. For an explanation of the information displays, refer to Paragraph 4.3.9.

4.3.14 MAIN PANEL DSKY MODE AND CONDITION INDICATOR CONTROL. The main panel DSKY mode and condition indicator control functional block provides the switching necessary to initiate certain spacecraft mode selections and the control of the DSKY and main panel condition indicator display panels.

4.3.15 MAIN PANEL DSKY POWER SUPPLY. This power supply is identical to the navigation DSKY power supply. Refer to Paragraph 4.3.11 for a description.

4.3.16 MAIN PANEL DSKY UPLINK TELEMETRY SWITCH. The uplink telemetry switch is a two-position toggle switch used to block or accept the uplink telemetry data inputs to the AGC.

4.3.17 MAIN D & C CAUTION/WARNING PANEL AND LOWER D & C CONDITION ANNUNCIATOR PANEL. These indicator panels provide the astronaut with G & N system status and detected subsystem errors. The lower D & C condition annunciators are located directly above the optical unit front panel. The main D & C Caution/Warning panel is located on the main display and control panel directly above the main panel DSKY. Some of the indicators of these panels receive inputs directly from the AGC and indirectly from the AGC through the mode and condition indicator control functional blocks. These indications are discussed (listed with their functions) in Table 4-3.

Table 4-3 - Condition Annunciator Panel

Indicator	Function	Location
G & N Error	Indicates that an error has been detected by one of the G & N monitors.	MAIN D & C
Computer Power Fail	Indicates a failure of the AGC +3 vdc or +13 vdc, power supply or the +28 vdc prime power.	MAIN and LOWER D & C
Master ALARM	Associated with the spacecraft master caution system.	LOWER D & C
IMU Fail	Indicates a stabilization loop failure (indicator is not illuminated during coarse align because large gimbal servo errors are normal in this mode).	MAIN and LOWER D & C
CDU Fail	Indicates that the digital encoder excitation power or the CDU motor excitation power has failed, or that there is a large CDU servo error (indicator is not illuminated during zero encoder when a large CDU servo error is normal).	MAIN and LOWER D & C
Accelerometer fail	Indicates that an accelerometer error signal is abnormal.	MAIN and LOWER D & C
Zero encoder	Indicates that the system is in the process of synchronizing the computer counters to the CDU shaft positions.	LOWER D & C

4.4 COMPUTER SUBSYSTEM OPERATIONS

The CSS interfaces with the ISS, OSS, astronaut and certain spacecraft systems. These interfaces are described in the paragraphs below.

4.4.1 CSS/ISS OPERATIONS. The CSS receives changes in CDU positions and changes in velocity from the ISS. These changes are accumulated in the AGC. The CDU positions are used by the AGC to monitor platform orientation. The velocity changes are used by the AGC to calculate the velocity and, by integration, the position of the spacecraft. The AGC also monitors the ISS moding and certain subsystem components for failures. The components monitored are:

a. CDU loops

b. Accelerometer loops

c. Stabilization loops

d. Power supplies

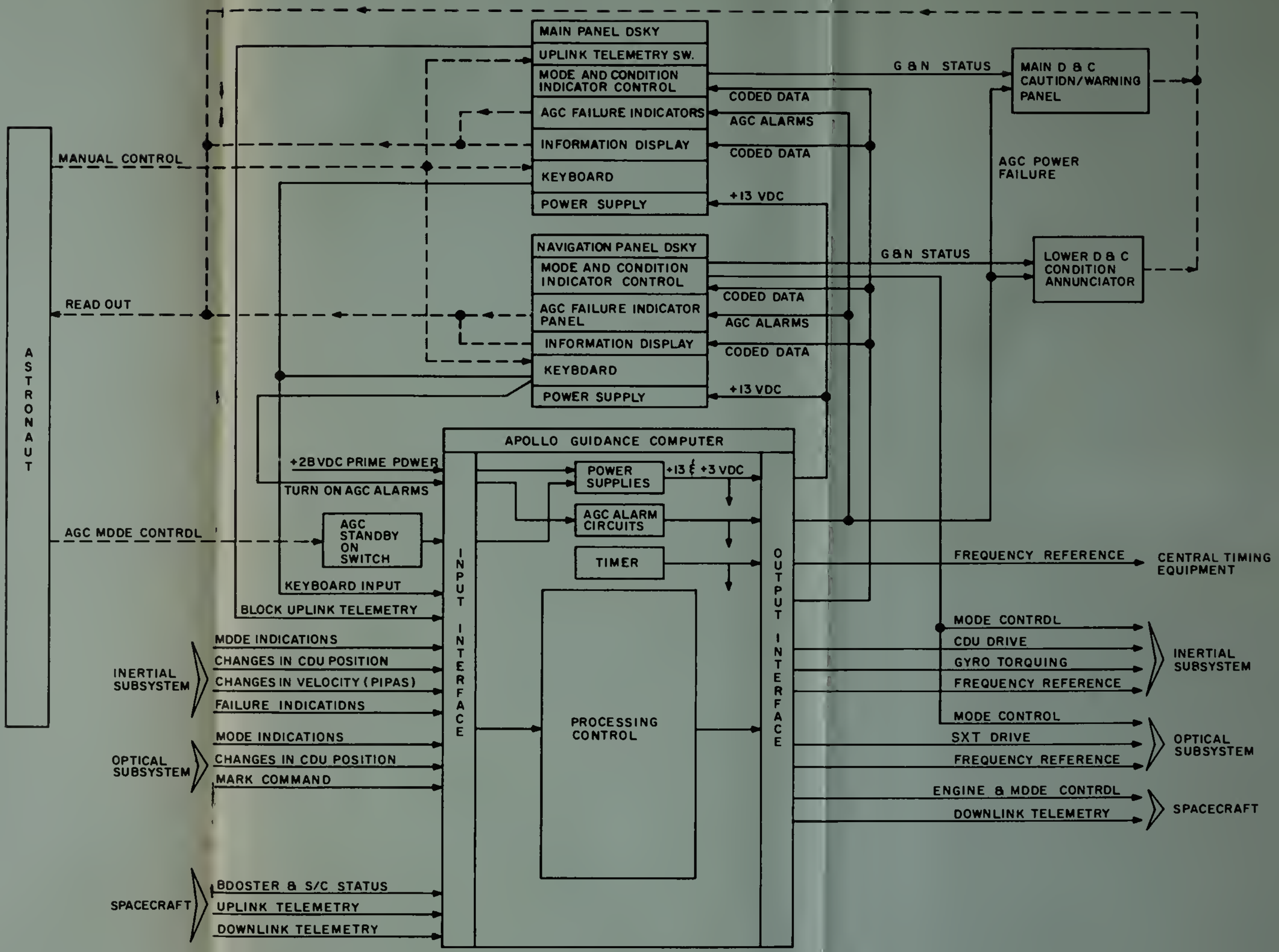


Figure 4-4. Computer Subsystem Interface

If an ISS mode is manually commanded, the AGC sets its DSKY command relays to agree with the ISS mode relays. If an ISS component fails, the AGC will energize the appropriate DSKY relays which will cause a condition indicator to light. The CSS also provides torquing signals to the IMU. These signals are used to align the stable platform. When the G & N system is under AGC control, the ISS moding can also be controlled by the AGC. A frequency reference is supplied to the ISS power supplies and torquing circuits.

4.4.2 CSS/OSS OPERATIONS. The AGC receives changes in CDU angles from the OSS and accumulates these angles, which are indicative of the sextant shaft and trunnion angles. These inputs, along with other information supplied by the AGC, are used to calculate the actual spacecraft position or orientation in space. Then, depending on the AGC program, the AGC either compares the actual spacecraft position to the calculated position or develops ISS torquing signals to align the IMU stable member. The AGC records these CDU angles whenever a MARK command is present. The OSS modes are monitored by the AGC in the same manner as those of the ISS. When the AGC is in control of the OSS, the AGC can command certain optical modes and can drive the sextant and telescope to particular star fields. A frequency reference is also supplied to the OSS power supplies.

4.4.3 CSS/ASTRONAUT. The CSS interface with the astronaut is through the DSKY's. The operator of the DSKY can communicate with the AGC by the depression of a sequence of keys on the DSKY keyboard. Each depression of a key inserts a five bit code into the AGC. The AGC responds by returning a code to the DSKY, which controls the display on a particular display panel, or by initiating an AGC operation. The AGC is also capable of initiating a display of information or a request for some action to the operator under its own initiative.

The basic communication language used in the interchange of information is a pair of words known as the VERB and NOUN. Each of these words is represented by a two digit octal code. The VERB code specifies that an action of some sort is to be performed while the NOUN code, used in conjunction with the VERB code, specifies on what the action is to be performed. An example of a VERB-NOUN code combination is given below:

VERB 16 -- MONITOR IN DECIMAL ALL COMPONENTS OF -- NOUN 21 -- PIPA'S

This combination of VERB-NOUN codes causes the accumulation of PIPA counts (as accumulated by the AGC) from each of the PIPAS to be displayed in R_1 (X PIPA), R_2 (Y PIPA) and R_3 (Z PIPA).

The standard procedure of inserting the VERB-NOUN codes via the keyboard is the depression of seven keys in a sequence. Using the VERB-NOUN codes previously discussed, the sequence of key depressions is as follows:

1. VERB
2. 1
3. 6
4. NOUN
5. 2
6. 1
7. ENTER

Depressing ENTER key indicates to the AGC that it should perform the operation indicated by the VERB-NOUN codes.

An alternate sequence of key depressions, which would accomplish the same insertion of information, is as shown below:

1. NOUN
2. 2
3. 1
4. VERB
5. 1
6. 6
7. ENTER

Whenever the VERB key is pressed, the two VERB display panels are blanked. Then, as the digits of the VERB code are keyed in, the digits are displayed in the two VERB display panels. For example:

VERB key pressed -- VERB display panels V_1 and V_2 blanked

1 key pressed -- 1 displayed in V_1

6 key pressed -- 6 displayed in V_2

Whenever the NOUN key is pressed, the two NOUN display panels are blanked. As the two digits of the NOUN code are keyed in, the NOUN display panels display the digits of the NOUN code.

If the VERB-NOUN codes, displayed in the VERB-NOUN display panels, are those desired for the next entry of information, the VERB-NOUN codes need not be keyed in again. All that is required is the depression of the ENTER key. This indicates to the AGC to use these codes again.

Prior to pressing the ENTER key, after entering the proper VERB-NOUN codes, the VERB-NOUN codes should be verified. If they are not verified, the wrong action could be initiated which might cause damage to the overall system operation.

Some VERB-NOUN codes require more information to be keyed in other than the VERB-NOUN codes. If more data is required, after the depression of the ENTER key, following the keying in of the VERB-NOUN codes, the VERB-NOUN display panels flash on and off at a 1.5 cps rate. These display panels continue to flash until all the information associated with the VERB-NOUN code has been keyed in. For example, using VERB 21 (WRITE 1ST COMPONENT INTO) NOUN 16 (TIME IN SECONDS), the entry sequence is as follows:

1. VERB
2. 2
3. 1
4. NOUN
5. 1
6. 6
7. ENTER

After the ENTER key is pressed, the VERB-NOUN display panels flash 21 and 16, respectively. This indicates that more information is required. In this case, it is a time in seconds. Assuming that the time to be entered is +75.25 seconds, the entry procedure is as follows:

1. +
2. 0
3. 7
4. 5
5. 2
6. 5
7. ENTER

After the ENTER key is pressed, the VERB-NOUN display panels stop flashing and remain on displaying VERB 21, NOUN 16. As the various keys are pressed while inserting the data, the digits are displayed in positions of one of the display registers, corresponding to the order in which they were entered. For instance, when +75.25 seconds is being entered, the + key is pressed first and + is displayed in R1S (Register 1, Sign Digit). The 0 key is pressed and 0 is displayed in R_1D_1 (Register 1, Digit 1). The 7 key is pressed and 7 is displayed in R_1D_2. This continues until the information is completely keyed in. Pressing the ENTER key, after keying the desired information, not only stops the flashing of the VERB-NOUN display but indicates to the AGC that it should proceed and perform the operation specified.

VERB 21 (WRITE 1ST COMPONENT INTO) 22 (WRITE 2ND COMPONENT INTO) 23 (WRITE 3RD COMPONENT INTO) 24 (WRITE 1ST AND 2ND COMPONENTS INTO) and 25 (WRITE 1ST, 2ND AND 3RD COMPONENTS INTO) are used to enter one, two or three components or portions of data into the AGC. For example, when VERB 25 (WRITE 1ST, 2ND AND 3RD COMPONENTS INTO) is entered, the VERB display will illuminate and display 25. When the ENTER key is pressed, after keying in the VERB-NOUN code, the VERB displayed is 21 (WRITE 1ST COMPONENT INTO) flashing. After the first portion has been keyed in and displayed in R_1 and the ENTER key pressed, the VERB displayed is 22 (WRITE 2ND COMPONENT INTO) flashing. After the second component or portion of the data is keyed in and displayed in R_2, the ENTER key pressed and the VERB displayed is 23 (WRITE 3RD COMPONENT INTO) flashing. After third component of data is entered and displayed in R_3, the ENTER key is again pressed and the VERB display stops flashing and the AGC proceeds to use the information entered.

Any time prior to pressing the last ENTER in the loading sequence, i. e., the ENTER after the third component was inserted in the previous paragraph, erroneous information can be corrected. To correct erroneous data, the CLEAR key is used. This key causes the display register, R_1, R_2 or R_3, last loaded, to be cleared and also clears the corresponding information loaded into the AGC. For example, if a three component load is being keyed in and it is discovered that an error exists in the first component of data R_1, after R_3 has been loaded but prior to the last enter, the following must be done to correct the data:

Depress CLEAR key -- R_3 blanked (VERB 23 remains displayed)

Depress CLEAR key -- R_2 blanked (VERB 22 is displayed)

Depress CLEAR key -- R_1 blanked (VERB 21 is displayed)

Reload R_1, R_2 and R_3

The CLEAR key is not used to clear the VERB, NOUN or **PROGRAM** displays.

Decimal and octal displays or loading are distinguished by use of the + and - displays or key inputs. Whenever decimal data is to be loaded, the + or - key must be depressed prior to keying in the digits of the data to be loaded. If the sign keys are not used, the data is assumed to be in octal form by the AGC. Whenever data is displayed using a sign, + or -, the displayed data is in decimal. Otherwise, when the sign is not used and R1S, R2S or R3S (REGISTER R1, R2 and R3 sign digits) are blanked, the data is in octal.

Whenever a display type VERB is used, the requested data is transferred to the DSKY display panels only once for every time the data is requested. Monitoring type VERBS, in contrast, are periodically updated, and the display of the requested data changes as the requested data in the AGC changes. The updating of the displayed data for a monitor type VERB is accomplished approximately every 1/2 second. (In future programs, the monitor rate is once per second.)

The major mode refers to system operations in the various phases of a flight or while operating on the ground. Examples of major modes are: system test, prelaunch alignment, orbital integration, etc.

In order to request that the system initiate one or more of these major modes of operation, a different sequence of entering information through the DSKY is required. The procedure is as follows using VERB 37 (CHANGE MAJOR MODE TO):

1. VERB
2. 3
3. 7
4. ENTER

When the ENTER key is pressed, after keying in VERB 37, the VERB display panels flash and the NOUN display panels are blanked. Now the two digit octal code for the desired major mode and phase of the major mode can be entered through the keyboard. As the appropriate keys are pressed, the digits of the code are displayed in the NOUN display panels. When the ENTER key is pressed after keying in the two code digits, the major mode code is displayed in the two PROGRAM display panels M_1 and M_2. If the operator wants to initiate the major mode prelaunch alignment which uses code 01, the following keying sequence must be used:

1. VERB
2. 3
3. 7
4. ENTER
5. 0 entry, for prelaunch alignment mode request
6. 4 entry, indicating phase to enter prelaunch alignment
7. ENTER

The two program display panels now display 01.

Another group of VERBS enables the operator to initiate system tests and modes of operation. Examples of these are:

PERFORM GYRO DRIFT TEST -- VERB 70

FINE ALIGN IMU -- VERB 42

ZERO -- VERB 40

Some of these VERBS do not require an associated NOUN code. For example, if the gyro drift test is to be initiated, the procedure is:

1. VERB
2. 7
3. 0
4. ENTER

This causes the system to enter the gyro drift test. Other VERBS do require NOUN codes, such as VERB 40 (ZERO). This VERB refers to CDUs and the NOUN code required with this VERB code specifies either the inertial or optical CDUs (NOUN 20, inertial CDUs; NOUN 55, optical CDUs). If it is desired to ZERO the inertial CDUs, the keying procedure is:

1. VERB
2. 4
3. 0
4. NOUN
5. 2
6. 0
7. ENTER

Display and monitoring of various data can be accomplished by the AGC on its own initiative, without requests for the data by the operator. The appropriate VERB-NOUN codes are displayed with the data so that it can be properly identified and used by the operator. Whenever the AGC has initiated the display or monitoring of some data, the data is displayed for at least 10 seconds. After this time duration, the AGC is free to change the data displayed, if it so desires.

The AGC is also capable of requesting the operator to perform an action. The action that is requested is usually specified by a combination of VERB-NOUN codes and additional information displayed in one or more of the display registers, R_1, R_2 and R_3. For example, if VERB 50 (PLEASE PERFORM) NOUN 25 (CHECKLIST) is displayed in the VERB-NOUN display panels, R_1 will display a numerically coded checklist item. When the operator has performed the requested action, the ENTER key is pressed. This indicates to the AGC that the operation has been completed. If the operator does not wish to perform the action requested, he may use VERB 33 (PROCEED WITHOUT DATA) or VERB 34 (TERMINATE). These VERB codes indicate to the AGC to continue without the data or requested action as best it can or to terminate the function it is trying to do.

While the operator of the DSKY is using the DSKY to load, display, etc., the AGC cannot interrupt this process. An interlock is set up by the AGC inhibiting itself from using the DSKY. Therefore, the DSKY operator should remove this interlock when he is finished using it. This is accomplished by either pressing the KEY RELEASE key or by entering VERB 35 (RELEASE DISPLAY SYSTEM). Both of these actions remove the DSKY-OPERATOR interlock and enable the AGC to use the DSKY. VERB 35 is included because early keyboards did not have a KEY RELEASE key.

The AGC is capable of requesting that the DSKY operator release the DSKY so the AGC may use it. This indicates that the AGC has some data to display to the operator and is accomplished by illuminating the KEY RELEASE panel on the DSKY condition indicator panel. The operator does not have to release control of the DSKY if he wishes to continue to use it.

As previously mentioned, when the AGC has initiated a display of data, the data is displayed for at least 10 seconds before the AGC is able to display some different data. This is an interlock the AGC imposes on itself to enable the operator time enough to read the data displayed. After 10 seconds have elapsed, the AGC drops the interlock or inhibit and is free to display different data to the operator.

4.4.4 CSS/SPACECRAFT SYSTEMS. The CSS interfaces with the SATURN instrumentation unit, stabilization control system (SCS), central timing equipment (CTE), mission sequencer, and the communications and instrumentation system (C&IS). These interfaces are discussed in the following paragraphs.

4.4.4.1 CSS/SATURN Instrumentation Unit. From the instrumentation unit, the CSS receives indications of lift-off and guidance release. When the CSS, which has maintained the stable member earth referenced, receives the guidance release signal, the AGC gyro torquing routine is halted and the ISS stable member is inertially referenced. The AGC then starts calculating spacecraft position and velocity. When the lift-off signal is received, the AGC begins torquing the ISS CDU's to follow the nominal boost trajectory, and it monitors the boost phase of the mission.

4.4.4.2 CSS/SCS. The CSS receives system mode indications from the SCS. The SCS receives thrust control commands from the AGC. When the G & N system is under CSS control, the AGC can command ISS modes which will cause the ISS to provide the error signals necessary for spacecraft attitude control to the SCS. The CSS can then initiate, monitor and terminate thrusting maneuvers through the SCS.

4.4.4.3 CSS/CTE. The CSS provides a 1.024 mc frequency reference to the CTE, which then synchronizes the CTE to the AGC timing circuitry.

4.4.4.4 CSS/Communications and Instrumentation System (C&IS). The CSS receives uplink telemetry data and downlink telemetry synchronization pulses from the C&IS. The uplink telemetry data is in the form of five bit codes which are identical to the key codes provided by the DSKY's. The operation of the CSS then can be controlled from the ground station via the uplink telemetry. There are two methods of inserting the uplink telemetry data into the AGC. One method is to insert all the uplink data required and thereby exert complete control of the CSS from the ground station. The other method is to insert all the uplink data except the final command for the AGC to process the data. The astronaut then has the option of using the uplink data or not. This data is displayed to the astronaut on the DSKY display panels for his inspection. The downlink telemetry sync pulses are used to regulate the gating of downlink telemetry data to the C&IS. The C&IS receives downlink telemetry data from the CSS. This data can be transmitted at 10 words per second or at 50 words per second (1.6 K bits per second or 51.2 K bits per second, respectively).

The ground station uses part of this downlink data to duplicate the displays and DSKY inputs that have occurred in the spacecraft. The ground station also has a duplicate DSKY so that the operator can send commands and data to the spacecraft through uplink telemetry system.

4.4.4.5 CSS/Mission Sequencer. The CSS receives an indication of command module - service module separation (the CSS has the capability of initiating this event) and of the SIVB separation.

4.4.5 AGC INFORMATION PROCESSING TECHNIQUE. The processing techniques used in the AGC enable it to process the required information on a timely basis. The various types of processing, the interlacing of program-controlled processing and processing functions are discussed in the following paragraphs.

4.4.5.1 Time Sharing the AGC Hardware. The AGC operates in an environment in which many parameters and conditions change in a continuous manner. The AGC, however, operates in a discrete, incremental manner, operating on only one item at any instant in time. Therefore, in order for the AGC to process the many parameters and conditions, and perform its function in the G & N system and spacecraft, the AGC hardware must be time shared. The time sharing of the AGC hardware is accomplished by assigning priorities to the various processing functions required of the AGC. These priorities are used by the AGC so that it processes the highest priority processing function required at any particular time.

4.4.5.2 Implementing the Time Sharing of the AGC. As previously stated, the basis for the time sharing of the AGC is the priority of the processing functions requiring processing. The implementation of the time sharing is accomplished through one of three methods which are:

a. A pure hardware function. (Counter interrupts)

b. A hardware and program control function. (Program interrupts)

c. A pure program control function. (Program controlled processing)

Each of these three groups has a relative priority with respect to the other groups or methods used in time sharing the AGC hardware; also, within each of the groups there are a number of processing functions, each having a priority level relative to the other processing functions within the group. The majority of the processing performed by the AGC falls into a pure program control processing category. In this category the AGC hardware is controlled by the program stored in the AGC's memory.

4.4.5.2.a Counter Interrupts. The processing performed by the AGC which is accomplished under control of the AGC circuitry is referred to as a counter interrupt. This processing handles items such as ΔV pulses from the PIPA's, $\Delta\theta$ pulses from the CDU's, Δ time pulses from the AGC timing circuitry, UPLINK telemetry data inputs and control pulse outputs from the AGC used to position the stable member of the IMU or the optical unit.

Whenever one of these pulse inputs is present, any other processing being performed by the AGC is temporarily suspended or interrupted. Then, the input pulse is processed under control of the AGC hardware. After the input pulse is processed, control of the AGC hardware is returned to the program controlled processing which was suspended. (See Figure 4-5) The processing of one of these input pulses requires approximately 12 microseconds.

Through the processing of the counter interrupts, the AGC accumulates data such as velocity, IMU gimbal angles, optical angles and the number of AGC pulse outputs developed to position the stable member or optical unit. Also, through this type of processing, the UPLINK telemetry data is converted from a serial to a parallel format for use in the AGC.

4.4.5.2.b Program Interrupts. The processing performed by the AGC which is controlled through both circuit and program controlled processing functions is referred to as a program interrupt. This type of processing is performed whenever a particular condition exists, either internal or external to the AGC. The conditions which cause a program interrupt are:

a. Time to process a program scheduled to be processed at a particular time.

b. Time to process a routine which performs AGC input/output functions.

c. An input from the DSKY keyboard.

d. A complete UPLINK word having been assembled in the AGC.

e. Time to load a new DOWNLINK telemetry word.

f. Process SATURN and spacecraft sequencing inputs.

The processing of one of these conditions is initiated whenever the condition exists. The initiation of the processing is accomplished by a circuit function which forces control of the AGC hardware to particular program controlled processing routine.

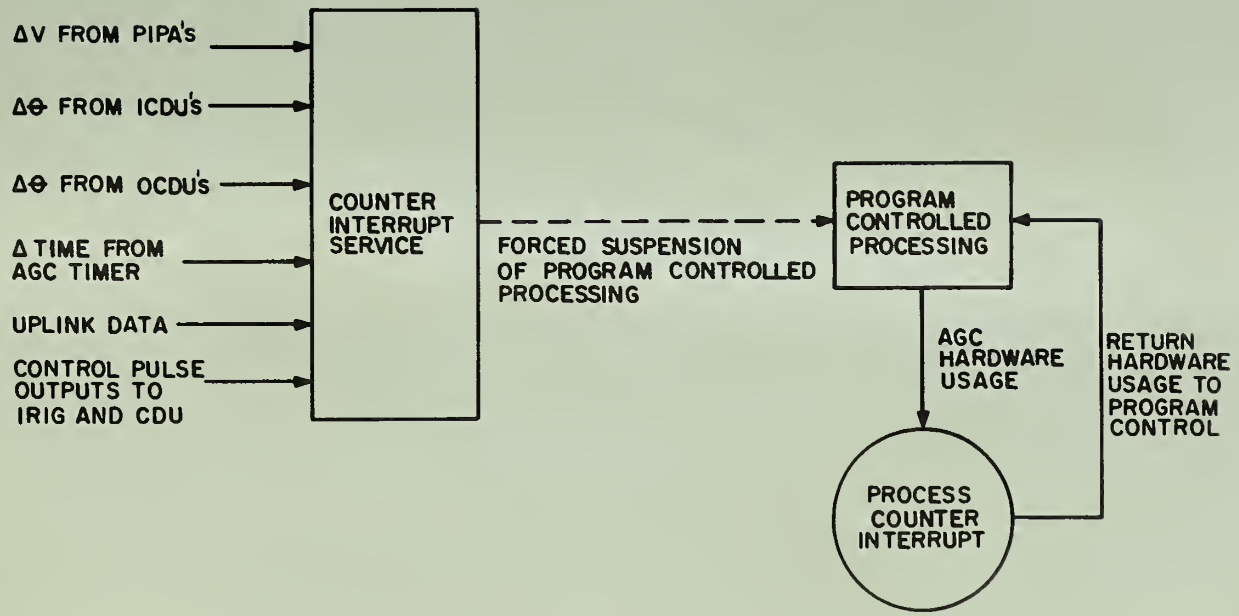


Figure 4-5. Counter Interrupt Processing

The processing of one of these conditions is initiated whenever the condition exists. The initiation of the processing is accomplished by a circuit function which forces control of the AGC hardware to particular program controlled processing routine. The program controlled processing function, being processed at the time when a program interrupt occurs, is suspended and control of the AGC is forced to the routine corresponding to the program interrupt condition which exists. (See Figure 4-6.) The program interrupt routine then processes whatever is required, depending on the program interrupt condition present. After completing the required processing for the program interrupt, control of the AGC hardware is returned to the suspended program. The maximum time that can be expended processing a program interrupt is 4 milliseconds.

4.4.5.2.c Program Controlled Processing. Most of the time, the AGC's hardware is controlled by the program stored in its memory. Of the many routines or processing functions that the AGC is capable of processing, some means must be employed to enable the AGC to process the routines required at any one time, and to process the most important required routine first.

In order for a routine or program controlled processing function to be performed, it must first be scheduled. The scheduling of a particular routine or processing function is a function of another routine or processing function. The scheduling also can be instigated through the DSKY's or UPLINK telemetry inputs. At the present time, the AGC is capable of having up to eight routines, usually referred to as "jobs," scheduled to be done at one time.

The job, which is processed out of the possible eight scheduled jobs, is determined by the priority numbers assigned to the jobs. If a job is scheduled having a priority higher than the job being processed, the AGC suspends the processing of the lower priority job and processes the higher priority job. When the higher priority job is completed, the control of the AGC hardware returns to the lower priority job at the point where it was suspended.

Using the scheduling of jobs and the priority assigned to the various jobs, the most important program controlled processing function is performed at any time.

4.5.5.2.d Relative Priorities of the Types of Processing. As previously stated, each of the three types of processing (counter interrupt, program interrupt and program controlled processing) have relative priorities. Of the three types, the counter interrupt processing is the highest priority processing function. A counter interrupt input, which requires processing, causes the processing of either a program controlled function or program interrupt to be suspended. After processing the counter interrupt, control is returned to the processing which was suspended. (See Figure 4-7.)

Program interrupts are the next highest priority type of processing. This type of processing causes the suspension of any program controlled processing. A program interrupt cannot interrupt or suspend the processing of a counter interrupt or the processing of another program interrupt. However, through program action, an inhibit can be set so that the program interrupt processing cannot interrupt the program controlled processing.

The program controlled processing is the lowest priority type of processing. Any counter interrupt or program interrupt processing causes the program controlled processing to be suspended. The exception to this, as stated above, is when the

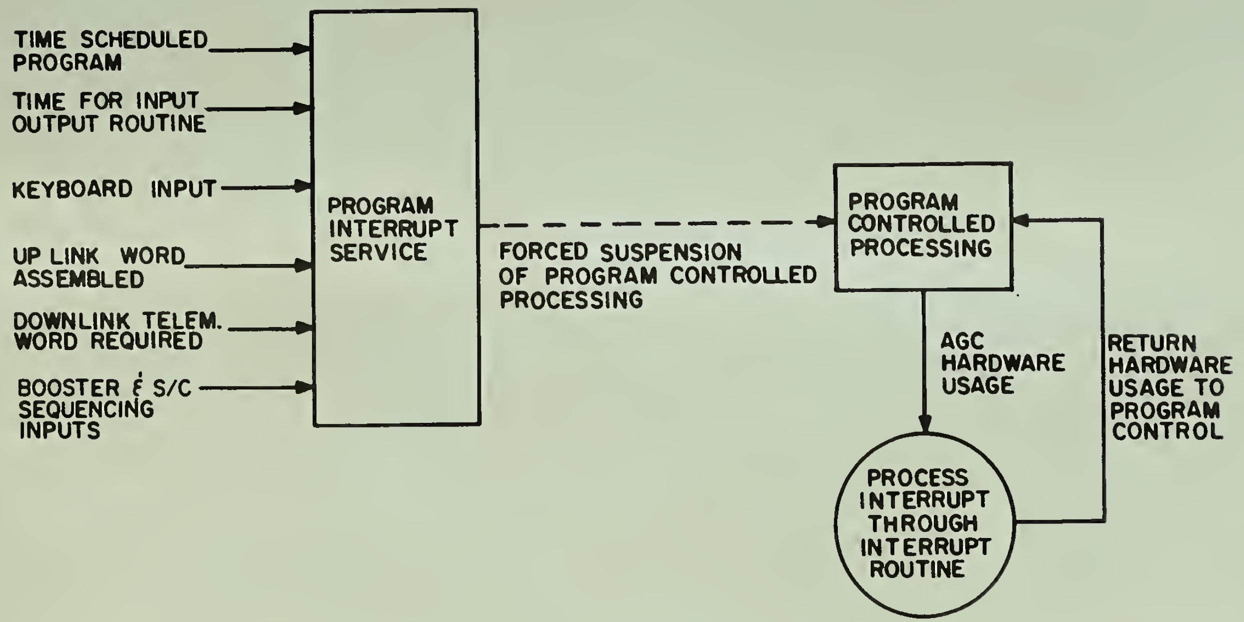


Figure 4-6. Program Interrupt Processing

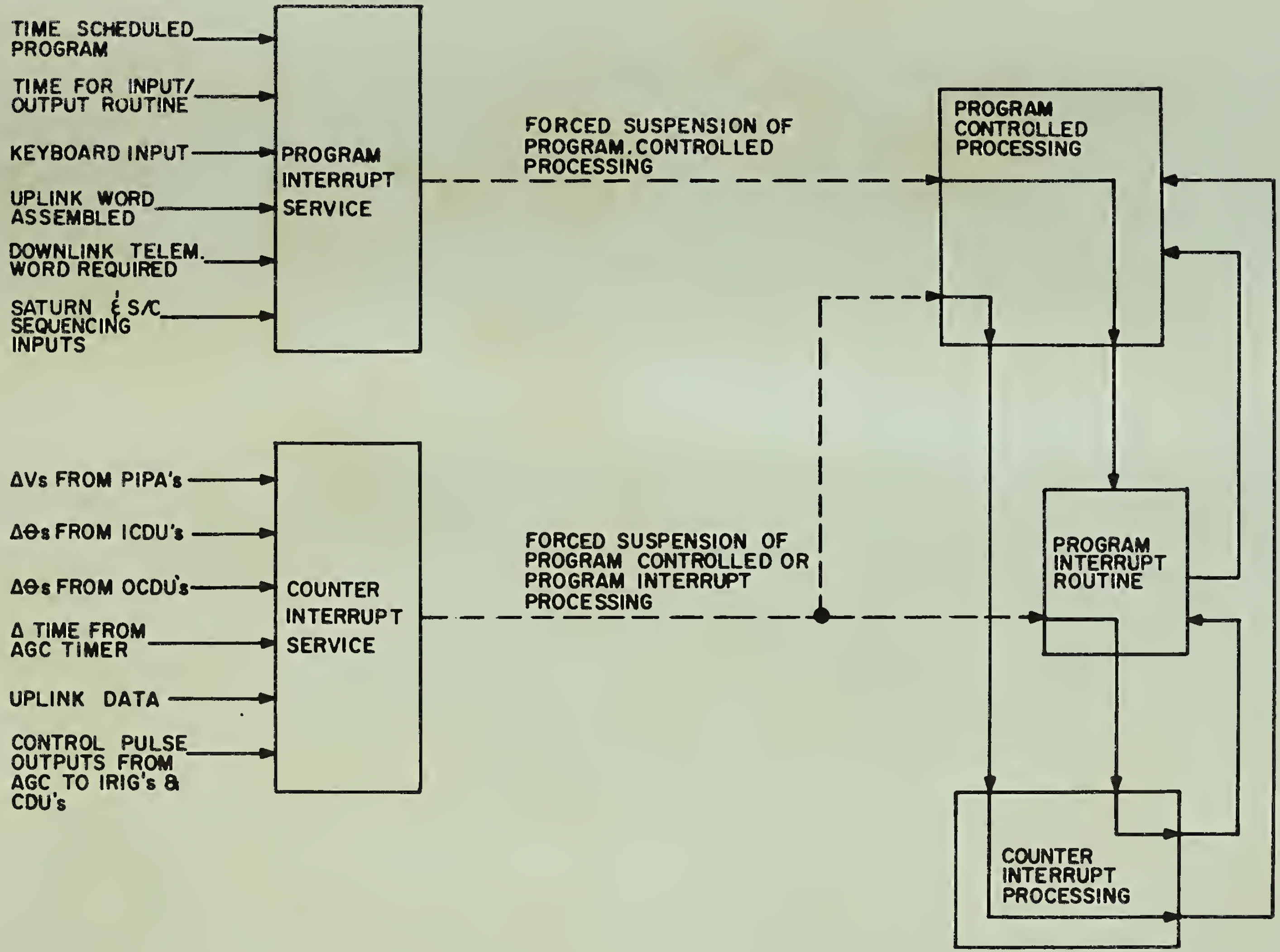


Figure 4-7. Counter and Program Interrupt Processing

honoring of a program interrupt is inhibited through program action. The program interrupts would be inhibited if some fairly critical function was being performed through program controlled processing.

4.4.5.3 Implementing Program Controlled Processing. (See Figure 4-8.) Time sharing of the AGC hardware among the program controlled processing functions, as previously stated, is based upon the scheduling and the priorities assigned to the various processing functions. The scheduling and the control required to process the highest priority scheduled job or processing function is provided for by a group of routines which form a category of executive control routines. All processing controlled through program action, with the exception of that processing controlled through program interrupt action, is in turn scheduled and controlled through these executive control routines.

4.4.5.3.a Executive Control Routines. The executive control routines of the AGC essentially provide the following functions for use by other AGC programs, routines, etc.:

a. Scheduling of a job to be processed.

b. Changing the processing control of a job to another job.

c. Terminating the processing of a job.

d. Deactivating a job.

e. Reactivating a job.

f. Controlling the restarting of a major mode or mission program.

Two types of scheduling are provided by the executive control routines. One type of scheduling provides for the execution of the job or processing function based on the priority of the scheduled job. The other type of scheduling provides for the execution of the processing function on a time dependent basis. Processing functions executed on the basis of time are referred to as "tasks" as opposed to those functions processed on the basis of program priority, which are referred to as "jobs."

A job or task, which wishes to schedule another job, uses one of the executive control routines to perform the scheduling function. The job which is scheduling another job supplies the executive routine with the priority of the job and specifies which job is to be scheduled. After scheduling, other routines of the executive control are used to control when the scheduled job is processed based on the priority of the job.

A job or task, which wishes to schedule another task, uses another executive control routine to perform the scheduling of the task or time-dependent processing. The job or task must provide this executive control routine with the time difference between present time and the time when the task is to be executed and which task is to be executed. The actual execution of the task is performed under control of one of the program interrupt routines known as the TIME 3 COUNTER program interrupt. The TIME 3 time counter of the AGC is used to time the execution of the task. It should be noted that the tasks or time dependent processing functions have, generally, a higher priority than jobs or processing functions whose execution is based on the assigned priority of the job.

Another executive control routine is used to terminate a particular job, whenever a job is completed, or in some cases, when a malfunction is detected. This routine removes the job from the scheduling list and also controls the initiation of the processing of the highest priority scheduled job.

The routine used to change processing control from one job to another is used whenever a job of higher priority than the job presently being processed is scheduled. The job of lower priority is suspended and left incompleted. After the higher priority job is completed, processing of the lower priority job is resumed at the point where it was suspended, provided a higher priority job is not scheduled.

The routine used to deactivate a job does not remove it from the scheduling list. The job, after being deactivated, remains scheduled but is in a nonactive state. By deactivating a job, jobs of a lower priority than that of the deactivated job can be processed. A job is usually deactivated when it must wait for data to be entered through the DSKY's, UPLINK telemetry or provided by another job, or if it must wait for a particular condition to exist or to control the basic iteration rate of a particular job. A job usually deactivates itself whenever any one of the above conditions exist. The deactivating of a job is referred to as "putting a job to sleep".

The routine used to reactivate a deactivated job is used by another job to "wake up the sleeping job" whenever one of the conditions stated above is available or present. When the job is awakened, and if its priority is the highest of all the scheduled jobs, processing of this reactivated job is resumed. If it is not the highest priority job scheduled, the processing of the higher priority job continues after the job has been reactivated.

The routine used to restart a major mode or mission program, during normal AGC operation, maintains a table of phase numbers associated with the various major mode programs. Each of the major mode programs is divided into phases and as the processing of the program progresses through its various phases, the phase table is updated. If a malfunction of a critical nature is detected which might have affected the processing of the program, a restart is performed. The phase number in the phase table is used to restart the processing of the major mode program at a particular phase of the program, dependent on the phase number. To assure against a failure associated with the phase number itself, the phase table is maintained in triplicate.

4.4.5.3.b Program Interrupt Routines. The names, causes and functions of the six program interrupts are as follows:

a. T3 RUPT (TIME 3 COUNTER PROGRAM INTERRUPT) is caused by a particular condition existing in the AGC's TIME 3 counter (overflow). This counter and its associated program controlled routine are used to initiate the time dependent processing functions (tasks) at the scheduled time.

b. RUPT 2 is caused by the inputs GUIDANCE RELEASE, SATURN ULLAGE, SIVB SEPARATE and SM/CM SEPARATE. This routine is used to perform the required actions according to the sequencing inputs. At the present time, this routine is not contained in the AGC program and the inputs are subject to negotiation.

c. T4 RUPT (TIME 4 COUNTER PROGRAM INTERRUPT) is caused by a particular condition existing in the AGC's TIME 4 counter. This counter is used to initiate the T4 RUPT routine every 60 milliseconds. The T4 RUPT routine performs the following input/output functions:

(1) Sets up conditions which enable the drive pulses for the optical and inertial CDU's.

(2) Sets up the relays in the DSKY's which control the display of information, control the moding of the ISS and OSS and control certain condition indicators.

(3) Performs mode sampling of ISS and OSS.

(4) Provides the logic for the IMU, PIPA, and CDU fail indications.

(5) Checks the DOWNLINK telemetry output word rate to assure a rate under 50 words/sec.

d. KEYRUPT (KEYBOARD PROGRAM INTERRUPT) is caused by the depression of a key on a DSKY keyboard, the depression of the MARK pushbutton, an automatic mark, or the depression of the MARK REJECT pushbutton. If the interrupt is caused by a keyboard input, this routine picks up the input code representing the key which was pressed and schedules the pinball program through the proper executive control routine. The pinball program assembles, interprets and initiates particular functions derived from keyboard entries. If the interrupt routine is initiated by a mark, either manual or automatic, the AGC records the optical and inertial CDU angles and the time when the mark took place. This information is used by the program which requested the mark. If the interrupt routine is initiated by a mark reject, the AGC erases the data recorded for the previous mark. The routine to handle the mark reject is not written yet.

e. UPRUPT (UPLINK TELEMETRY PROGRAM INTERRUPT) is caused by a particular condition existing in the AGC's uplink counter, which it uses to convert the serial input from the uplink telemetry system to a parallel word. This routine performs a check on the transmission of the uplink data and uses the portion of the keyrupt routine which schedules the pinball program through the executive control routines.

f. DNRUPT (DOWNLINK TELEMETRY PROGRAM INTERRUPT) is caused by a sync pulse (TELEMETRY END) from the downlink telemetry system. This pulse occurs at either a 50 or 10 pps rate and therefore the DNRUPT routine is executed 50 or 10 times/sec. The DNRUPT routine locates the proper AGC word which is to be transmitted next and loads it into the AGC circuitry from which the word is gated by the downlink telemetry system.

4.4.5.3.c Processing Controlled Through the Executive Routines. As was stated previously, most of the processing performed by the AGC is under program control and is executed under control of the executive routines. The following is a brief description of some of the programs, routines, etc., which fall into this category of processing and are used by or effect these programs, routines, etc.:

a. PINBALL: This program is used to assemble, interpret and initiate functions from the information entered through the DSKY's or the uplink telemetry system. As the information is entered, it supplies the required information for the display of the information to the T4 rupt routine, which drives the display portion of the DSKY. Besides providing these functions, the pinball program provides the internal AGC programs with the same capabilities of displaying information to the astronaut and initiating the functions which can be initiated by the astronaut through DSKY keyboard or uplink telemetry entries.

b. PRELAUNCH ALIGNMENT: The prelaunch alignment program is initiated through keyboard entries by the pinball program, which schedules it to be performed through the executive control routines on a program priority basis. This program aligns the stable member of the ISS to a specified orientation with respect to azimuth and to a specific orientation with respect to local vertical prior to launch. The prelaunch alignment program accomplishes this by utilizing previously loaded values for the desired azimuth angle, the latitude of the spacecraft (used to determine earthrate), gyro drift coefficients and the changes in velocity received from the PIPA's due to stable member orientation, with respect to the gravitational vector. The equations for this program use these quantities, along with time, to determine the number of torquing pulses required from the AGC to maintain the desired stable member orientation.

c. ORBITAL INTEGRATION: The orbital integration program is initiated by pinball as is the prelaunch alignment program. This program is used to calculate the spacecraft's velocity and position vectors during nonpowered flight. Also, it is used to predict the spacecraft's velocity and position at some time in the future. This is used to determine when and how much correction is required in the spacecraft's course. The program requires no inputs from the ISS and OSS to perform these calculations, although star sightings may be used to update the calculations. All that is needed by the program is an initial velocity and position. Using these quantities and time, the orbital integration program calculates the gravitational field the spacecraft is in. Based on this, it calculates the spacecraft's velocity and position as these vectors are influenced by the gravitational field.

d. PIPA SCALE FACTOR TEST AND IRIG COEFFICIENT TEST: The PIPA scale factor and IRIG coefficient tests are a portion of the system test routines incorporated in the AGC programs. These tests are used to determine if the PIPA scale factors are within tolerance and the drift rates of the IRIG's. In performing these tests, the AGC orientates the stable member of the ISS to particular positions and monitors the PIPA outputs.

e. DUMMY JOB AND AGC SELF-CHECK: The dummy job is a routine which the AGC uses whenever it has nothing else to do. This is essentially a waiting loop in which the AGC continuously checks to see if there is anything to do. An option of the dummy job routine is the AGC self-check. This option must be requested by the astronaut. The AGC self-check routine checks on various control pulses and operations of the AGC.

4.4.5.3.d Interrelationship of Processing Functions. The interrelationship of the processing functions contained within the AGC and all the combinations thereof becomes quite involved, voluminous, and is generally beyond the scope of this study guide. However, a fairly brief discussion, by example, is given in the following paragraphs.

This discussion attempts to show how the various processing functions are used in a relatively simple routine. The routine which is discussed is the zero encoder mode switching routine which is requested through DSKY keyboard or UPLINK telemetry inputs. Keep in mind, while studying the following paragraphs, that the processing of data through counter interrupt action is going on, whenever required, even though it is not discussed.

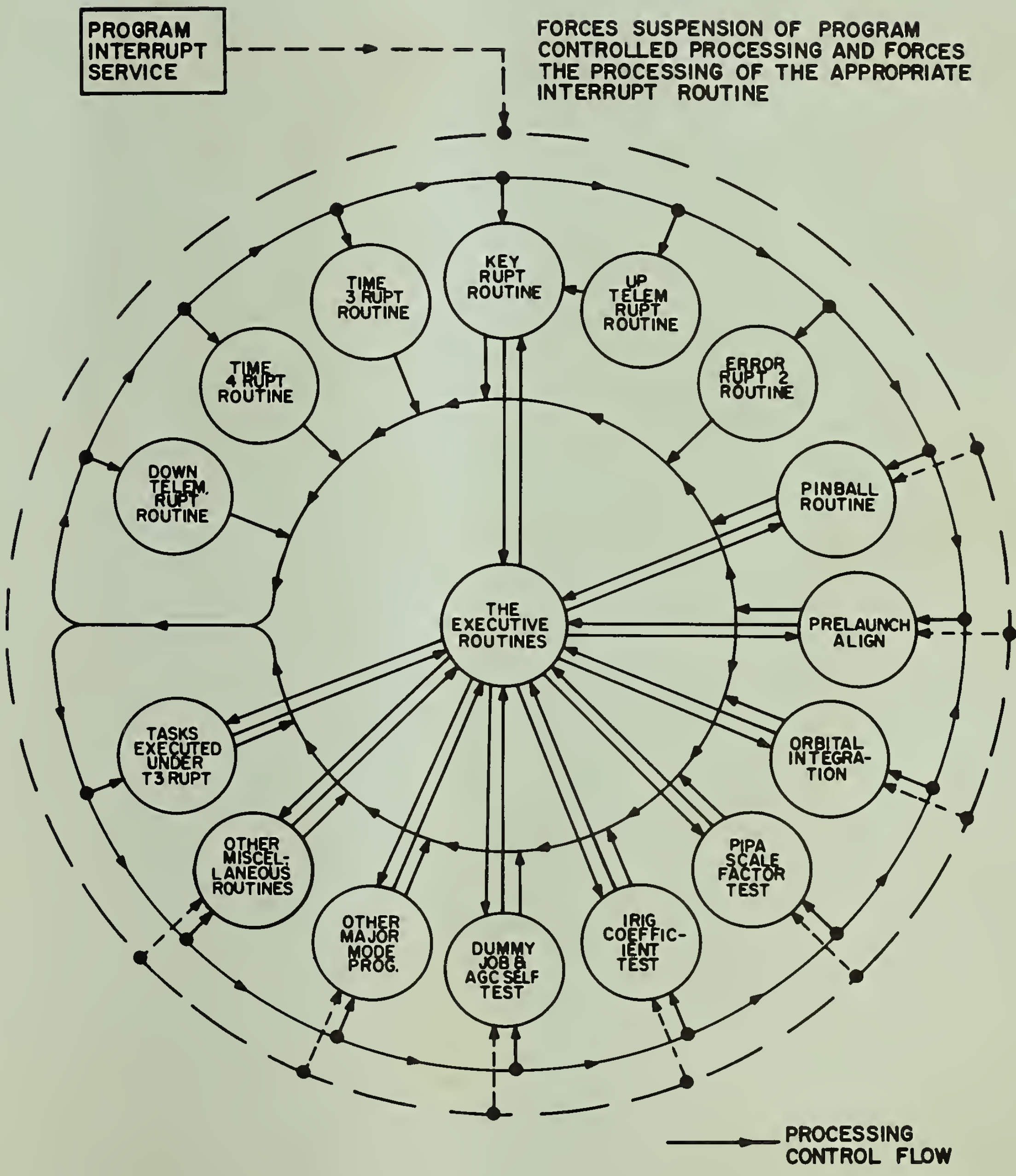


Figure 4-8. Program Controlled Processing

In order to request the zero encoder mode switching routine to be performed, the astronaut enters, through the DSKY keyboard, this sequence of key depressions: (1) VERB, (2) 4, (3) 0, (4) NOUN, (5) 2, (6) 0 and (7) ENTER. This sequence of entries indicates to the AGC that it should zero the inertial CDU's. VERB 40 states that CDU's should be zeroed while NOUN 20 specifies the inertial CDU's.

As each of the keys are depressed to enter the VERB-NOUN codes, the control of the AGC hardware is forced to the KEYRUPT routine. (See Figure 4-9.) The KEYRUPT routine furnishes the DOWNRUPT routine with the keycode input and uses the executive control routine to schedule the pinball program to be processed on a program priority basis. After the scheduling is completed, the executive control routine returns control to the KEYRUPT routine which returns control back to the processing function interrupted by the KEYRUPT.

Within 20 m.s. of the time the pinball program was scheduled, the processing of one of the routines of pinball is initiated under executive control, if pinball has the highest priority of the scheduled jobs. Pinball processes the input keycodes and furnishes the T4 RUPT routine with the data required for display of the keycode inputs. The T4 RUPT routine drives the DSKY displays with this information and also furnishes the DOWNRUPT routine with the same information for transmission by the DOWNLINK telemetry system. After pinball has completed the processing of each keycode input, the pinball job is terminated and control is returned to the next lower priority scheduled job under executive control.

Finally, when the ENTER key is pressed, the KEYRUPT routine is again initiated which again schedules the pinball program through the executive routines and returns control to the processing function which was interrupted. Again, within 20 m.s., pinball program processing is initiated if it is the highest priority scheduled job. With the ENTER keycode input, the pinball routine uses the assembled VERB and NOUN codes to transfer control to the ZERO ENCODER mode switching routine. This routine is executed under control of the scheduled pinball routine which is, in turn, executed under control of the executive routines.

The zero encoder mode switching routine initiates the ISS zero encoder mode which illuminates the ZERO ENCODER mode button on the IMU control panel and illuminates the ZERO ENCODER indicator on the lower D & C condition annunciator panel by providing the T4 RUPT routine with the required data. The T4 RUPT routine uses this data to drive the desired relays in the navigation panel DSKY which control these operations and also uses the mode data to verify that the desired ISS mode is achieved. The T4 RUPT routine supplies the DOWNRUPT routine with the mode and indicator data for transmission by the DOWNLINK telemetry system.

After initiating the zero encoder mode, a task, IMU ZEROED, is scheduled through the executive routine to be executed in 40 seconds. Then the routine puts the pinball job to sleep by using the executive routine and the processing of the next lower priority scheduled job is resumed. The 40 second delay, which was scheduled for executing the IMU ZEROED task, allows time for the CDU's to drive to their 0° position.

When 40 seconds of time has elapsed, the T3 RUPT routine is initiated, which in turn initiates the IMU ZEROED task. At this time, the CDU's will be at 0°, so, the IMU ZEROED routine sets the ISS CDU counters within the AGC to zero to assure that the AGC will have an accurate representation of the CDU angles. After this, a check is made to determine if the zero encoder mode switching was successful, prior to

continuing with the routine. Indication of the successful mode switching is supplied by the T4 RUPT routine, which verifies that the desired mode was achieved. Then, the ISS fine align mode is initiated by furnishing the T4 RUPT routine with the proper data. Another task, ZERO ATTITUDE CONTROL, is then scheduled through the executive routine to be executed in 10 seconds, after which, control is returned to the T3 RUPT routine, which returns control to the interrupted processing function. When the fine align mode is initiated, the CDU's drive back to the IMU gimbal positions. After 10 seconds, the T3 RUPT routine is initiated again and the task ZERO ATTITUDE CONTROL is initiated. First, the fine align mode switching is verified using the information supplied by the T4 RUPT routine. If the mode switching was not achieved, the pinball job is terminated. If the mode switching was good, the ISS attitude control mode is initiated and a desired CDU angle of 10° is supplied to the T4 RUPT routine, which drives the circuitry for the mode switching and develops the pulse outputs to drive the CDU's about 10°. (The CDU's are driven 10° to eliminate the possibility of a false null, which can occur if a gimbal is 180° from its zero position and the CDU is at its 0° position during zero encoder mode.)

After setting up the attitude control mode and CDU drive, another task, REFINE, is scheduled to be executed in two seconds. (This allows enough time for the CDU's to be driven to the 10° position to get the CDU out of the false null condition if it existed.) Then, control is returned to the T3 RUPT, which returns control to the interrupted processing function.

When two seconds have elapsed, the task REFINE is initiated by the T3 RUPT routine. The attitude control mode switching is verified from the data supplied by the T4 RUPT routine. If the mode switching was not achieved, the pinball job is terminated through the executive routine. If the mode switching was achieved, the fine align mode is initiated, again by supplying the T4 RUPT routine with the proper data. Then, still another task, IMU FINED, is scheduled to be performed in 20 seconds. After this, control is returned to the T3 RUPT routine, which returns control to the interrupted processing function.

After 20 seconds have elapsed, the IMU FINED task is initiated by the T3 RUPT routine. The fine align mode switching is verified and then the pinball routine, which was sleeping or deactivated during this time, is awakened using the executive routine. The IMU FINED task is terminated by returning control to the T3 RUPT routine, which returns control to the interrupted processing function.

Within 20 m. s., the executive routines return control to the pinball routine if its priority is the highest of the scheduled jobs. Pinball then calls on the executive routine to terminate itself. The executive routine then routes the control of the AGC to the next highest scheduled job. This ends the zero encoder mode switching routine.

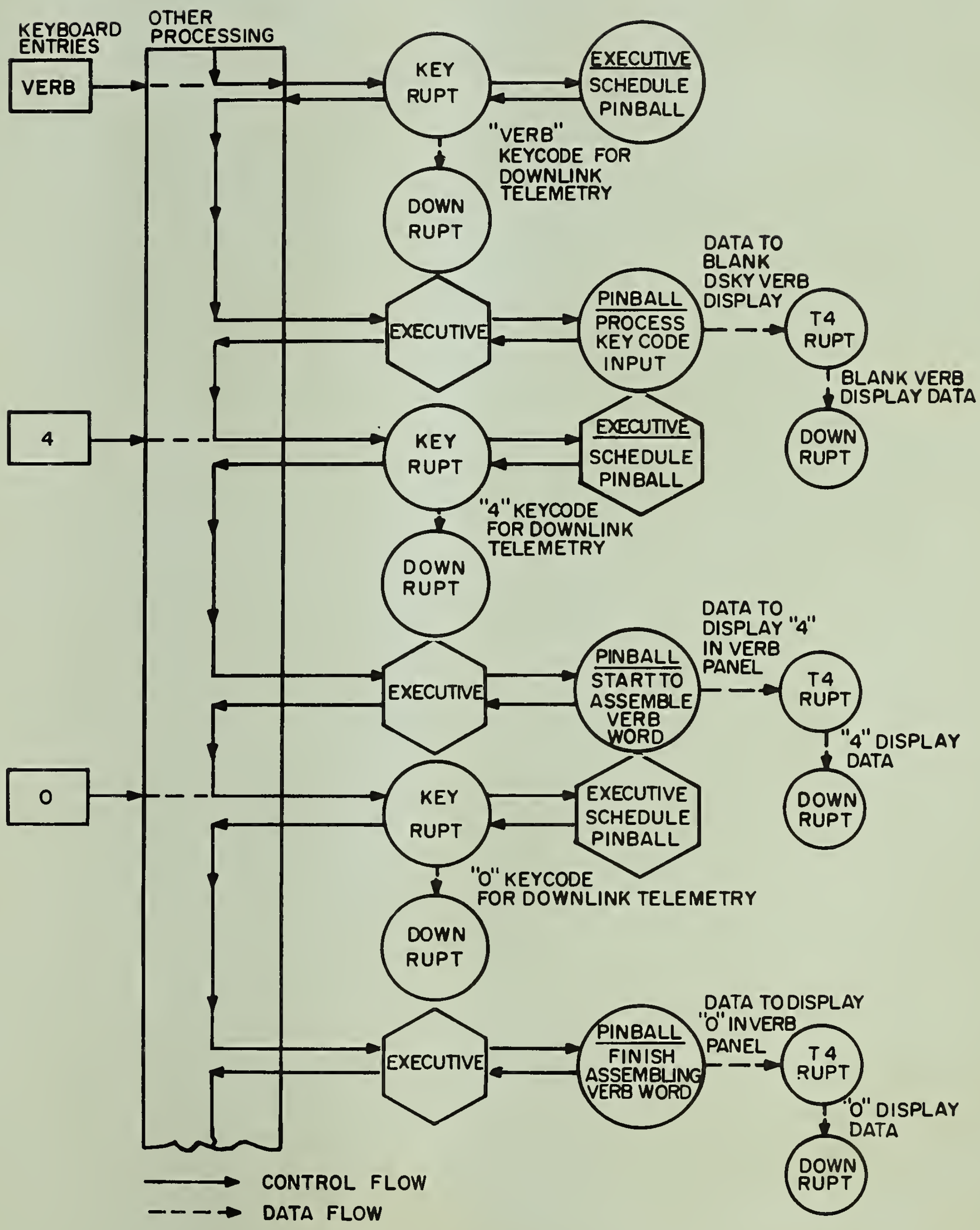


Figure 4-9. Zero Encoder Mode Switching Routine
(Sheet 1 of 4)

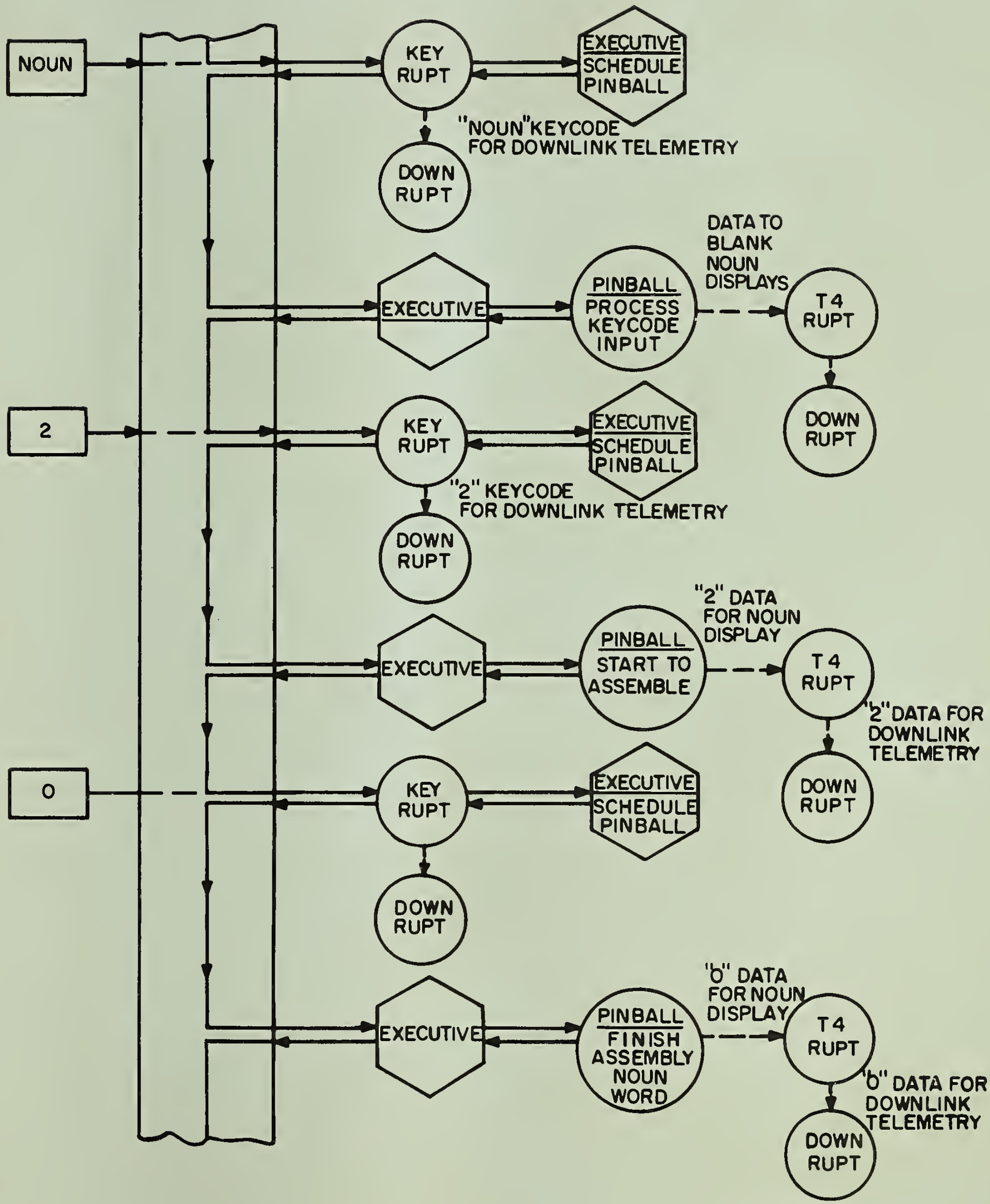


Figure 4-9. Zero Encoder Mode Switching Routine
(Sheet 2 of 4)

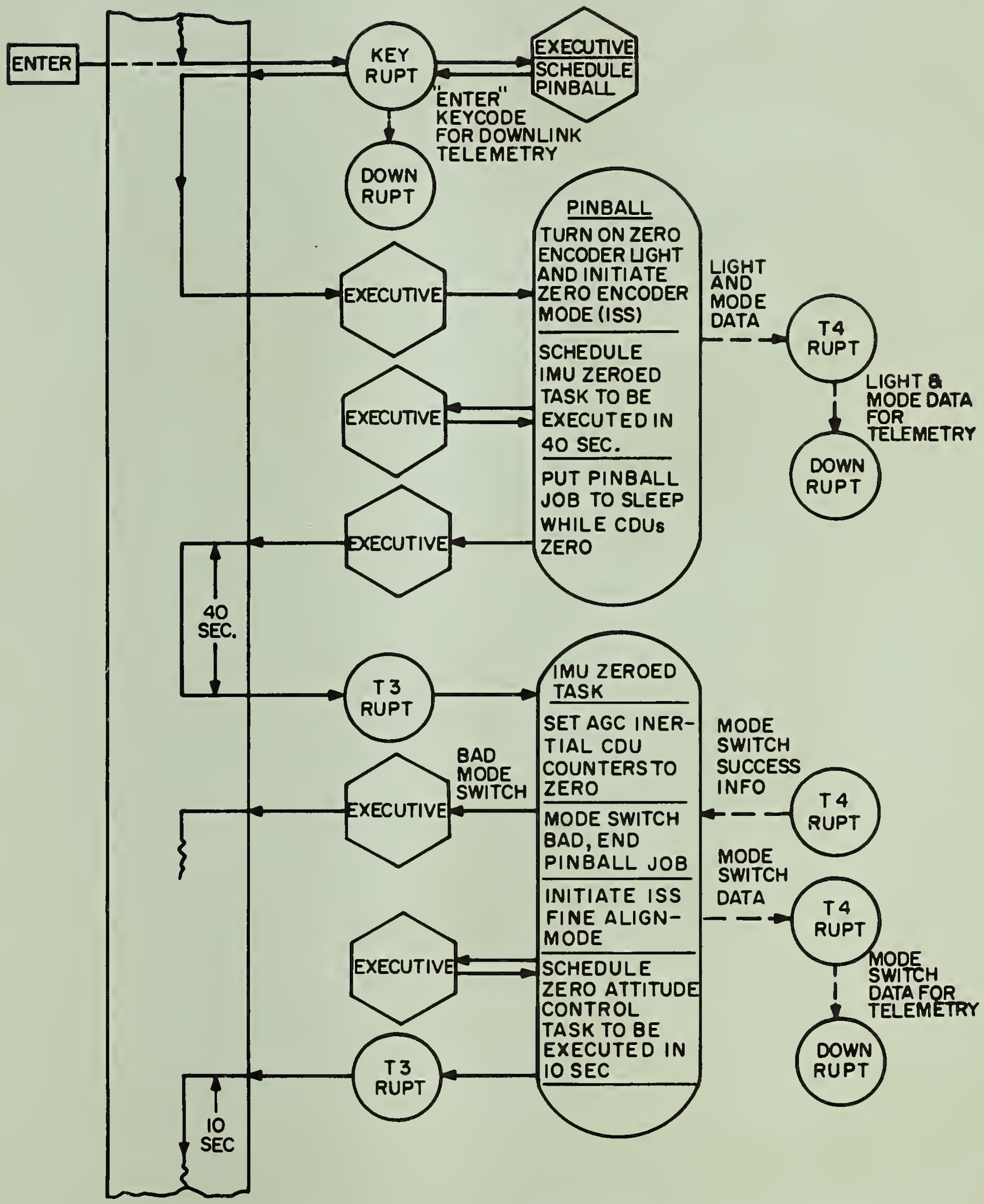


Figure 4-9. Zero Encoder Mode Switching Routine
(Sheet 3 of 4)

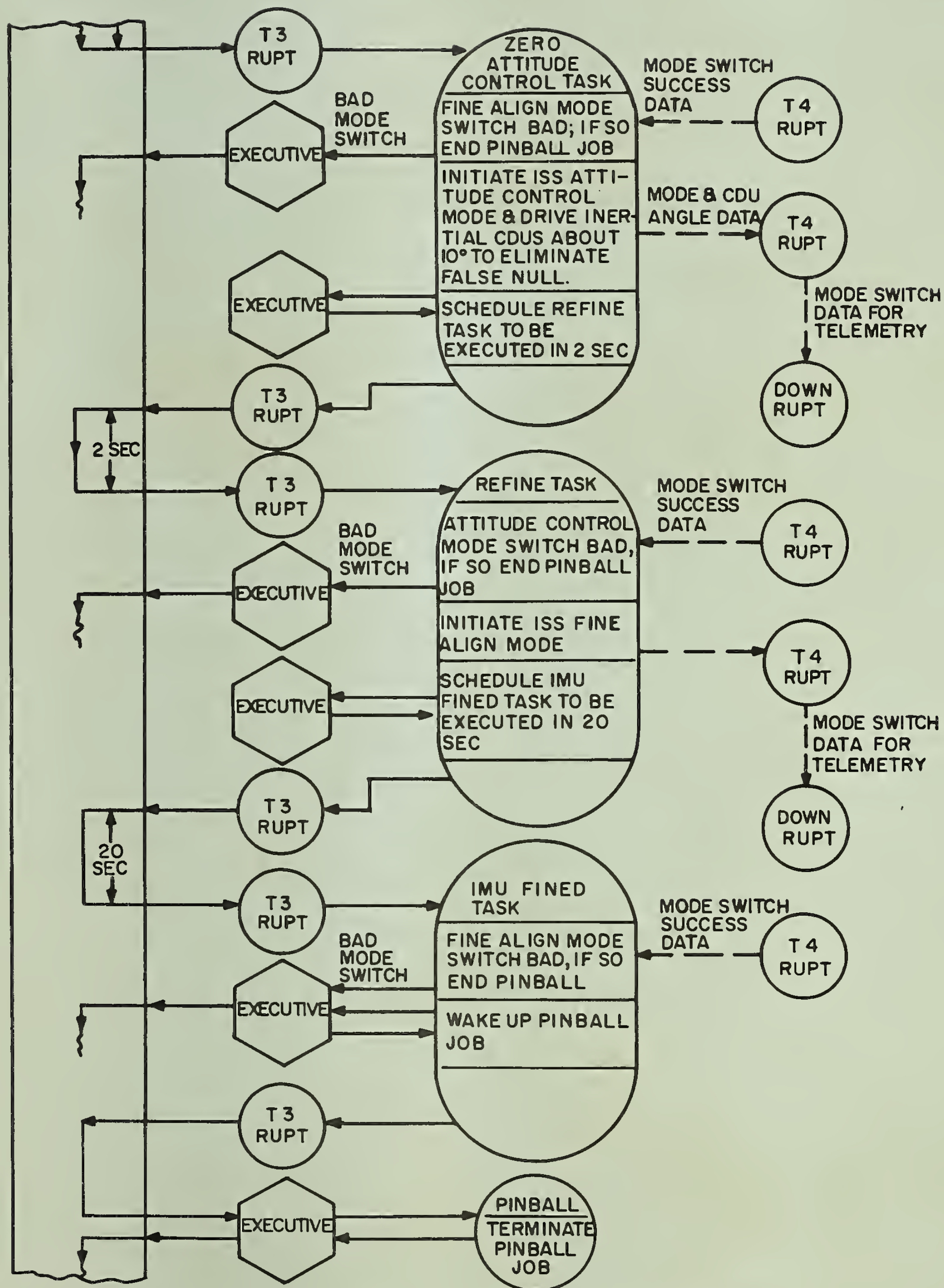


Figure 4-9. Zero Encoder Mode Switching Routine (Sheet 4 of 4)

4.5 SUMMARY

The computer subsystem (CSS) performs the following functions:

a. Solves the guidance and navigation problems for all mission phases.

b. Controls the G & N system as well as other spacecraft systems.

c. Displays pertinent information to the astronaut and the ground stations when requested.

d. Provides a means by which the astronaut or the ground stations can directly communicate with the G & N system.

The CSS consists of the Apollo guidance computer (AGC), a main panel DSKY and a navigation panel DSKY.

The AGC is a core memory, digital computer which serves as the central processing element of the G & N system. It permanently stores all the navigation tables, trajectory parameters, programs and constants necessary to solve the guidance and navigation problems. The AGC processes data and issues discrete control signals, both for the G & N system and other spacecraft systems. It is a control computer with many features of a general purpose computer. As a control computer, the AGC aligns the stable platform of the IMU, positions the optical unit and issues commands to the spacecraft. As a general purpose computer, the AGC solves the G & N calculations required for the Apollo mission. In addition, the AGC also monitors the operation of the G & N system.

The DSKY's provide a two way communications link between the astronaut and the AGC. Through this communications link the following functions can be performed:

a. Loading of data into the AGC.

b. Display of data from the AGC and of data loaded into the AGC.

c. Monitoring of data from the AGC.

d. Display of the AGC modes of operation.

e. System control.

f. Display of AGC requests to the operator.

REVIEW QUESTIONS FOR SECTION IV

1. The computer subsystem consists of what major components?

   a.

   b.

   c.

2. The ______________ provides a two way communications link between the astronaut and the AGC.

T F 3. The CSS is capable of positioning the IMU platform and the optical units.

T F 4. The CSS utilizes both fixed and erasable core memories.

T F 5. The CSS provides timing signals to the central timing equipment.

T F 6. The CSS receives uplink data from the ground stations through the C&IS.

7. The CSS hardware must be time ______________ to process the many parameters and conditions of the G & N system and other spacecraft systems.

8. When a keyboard pushbutton is pressed, a ____________ interrupt is initiated which causes the pushbutton 5 bit code to be processed.

9. What is a T3 RUPT caused by?

10. List two functions of a T4 RUPT.

    a.

    b.

SECTION V

G & N SYSTEM FUNCTIONS

INTRODUCTION

This section will present a brief description of the G & N functions for the Block I (Series 100) system. The functions are based on a lunar orbit flight of the command module even though the Block I (Series 100) system will be used only for earth orbit. The purpose for considering trans-coast and lunar orbit functions is that they may be practiced in earth orbit flights and therefore are necessary to show the complete G & N system capability. A simplified G & N system flow diagram is provided and described for each function. The objective of this material is to tie together the three subsystems and to show generally the computer operations and crew procedures for each major function performed by the G & N system.

5.1 PRELAUNCH IMU ALIGNMENT

In preparation for launch, the stable member is aligned and held earth referenced at a predetermined orientation. Since the G & N system monitors the saturn guidance during the booster phase, prelaunch IMU alignment is required. The stable member is aligned to a preferred orientation, in respect to the inertial frame, to establish a known initial alignment or starting point from which spacecraft velocity and position can be calculated by the G & N system.

Alignment consists of orienting the acceleration-sensitive axes of the stable member to an earth referenced coordinate system (see Figure 5-1). The alignment is performed in two steps: vertical erection and azimuth alignment. The vertical erection is performed by positioning the X accelerometer input axis along local gravity. The Z and Y accelerometer input axes are maintained in the horizontal plane at the launch point.

The stable member alignment is maintained by the computer. If the stable member drifts from preferred orientation, the outputs of the Y and Z accelerometers indicate a portion of local gravity. The 16 PIP outputs are applied to the computer, which utilizes the Y and Z accelerometer outputs to calculate the torquing pulses required to realign the stable member. The computer issues pulses to the torquing electronics which reposition the floats of the 25 IRIG's. The IRIG's generate an error signal to drive the stabilization loop, which repositions the stable member.

The azimuth of the stable member is maintained by gyro compassing (the desired azimuth will vary from 72° to 108° depending on the launch constraints). Gyro compassing is a self-alignment process based on the fact that the east 25 IRIG will sense a component of earth's rotation rate when the stable member is misaligned in azimuth. This component of earth rate will cause the stable member to tilt with respect to the earth. The Y and/or Z accelerometers, which were in a horizontal plane, will sense a gravity input. The accelerometer outputs are processed by the computer and torquing pulses issued which are applied to the 25 IRIG's to correct the stable member azimuth alignment. A torque bias input to the east 25 IRIG is required when an alignment other than due east is performed.

5.1.1 G & N SYSTEM FLOW. The computer and inertial subsystems are used during the prelaunch IMU alignment function with the G & N monitor mode selected on the SCS mode panel (see Figure 5-2). The inertial subsystem is cycled through the zero encoder, fine align, attitude control and coarse align modes into the fine align mode where it remains during vertical erection and gyro compassing of the IMU. Accelerometer outputs and gimbal angles from the CDU's are provided to the computer. The computer performs the moding of the inertial subsystem and positions the stable member. The navigator selects the required computer program and, if necessary, loads launch data into the computer by the keyboard.

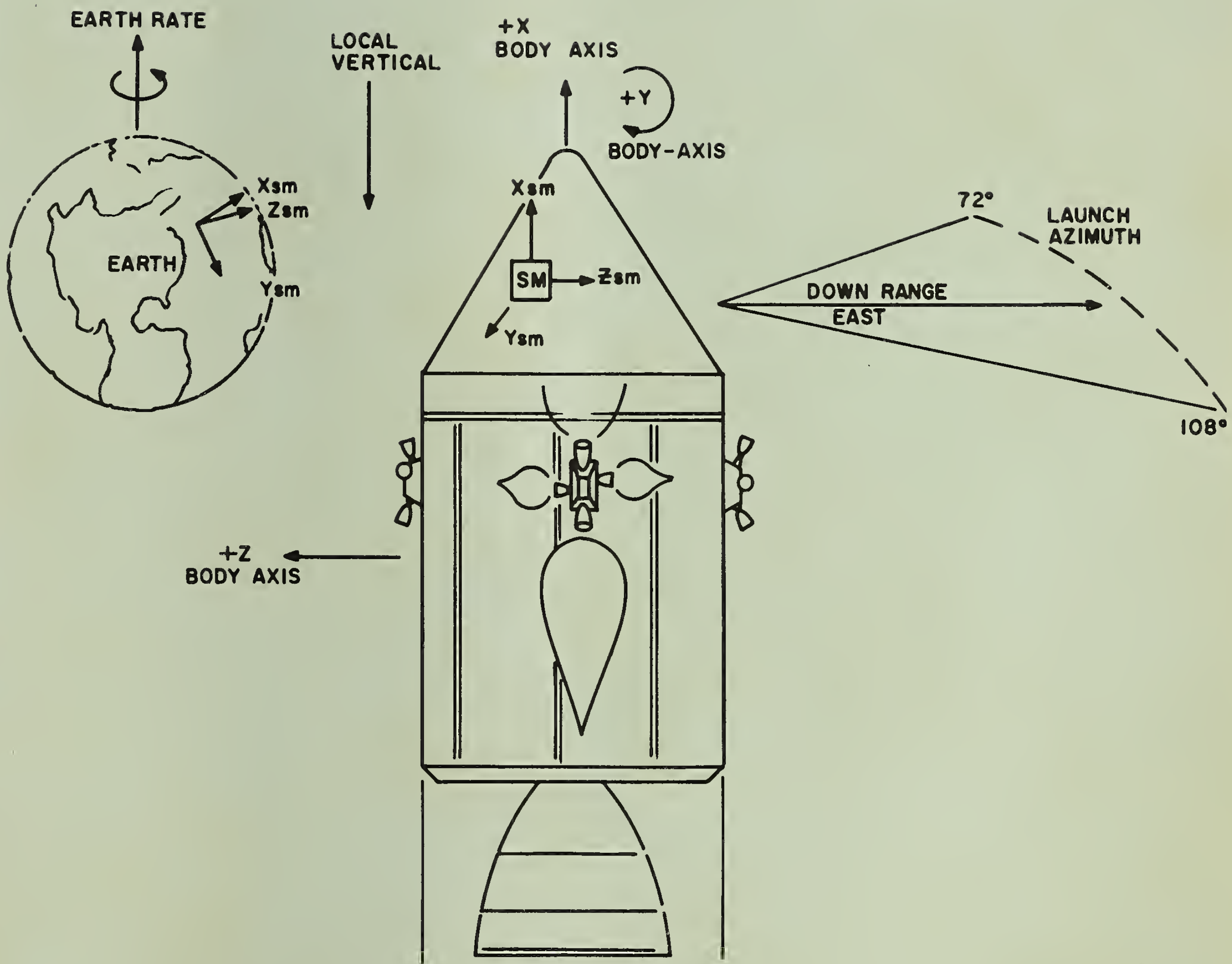


Figure 5-1. Prelaunch Alignment

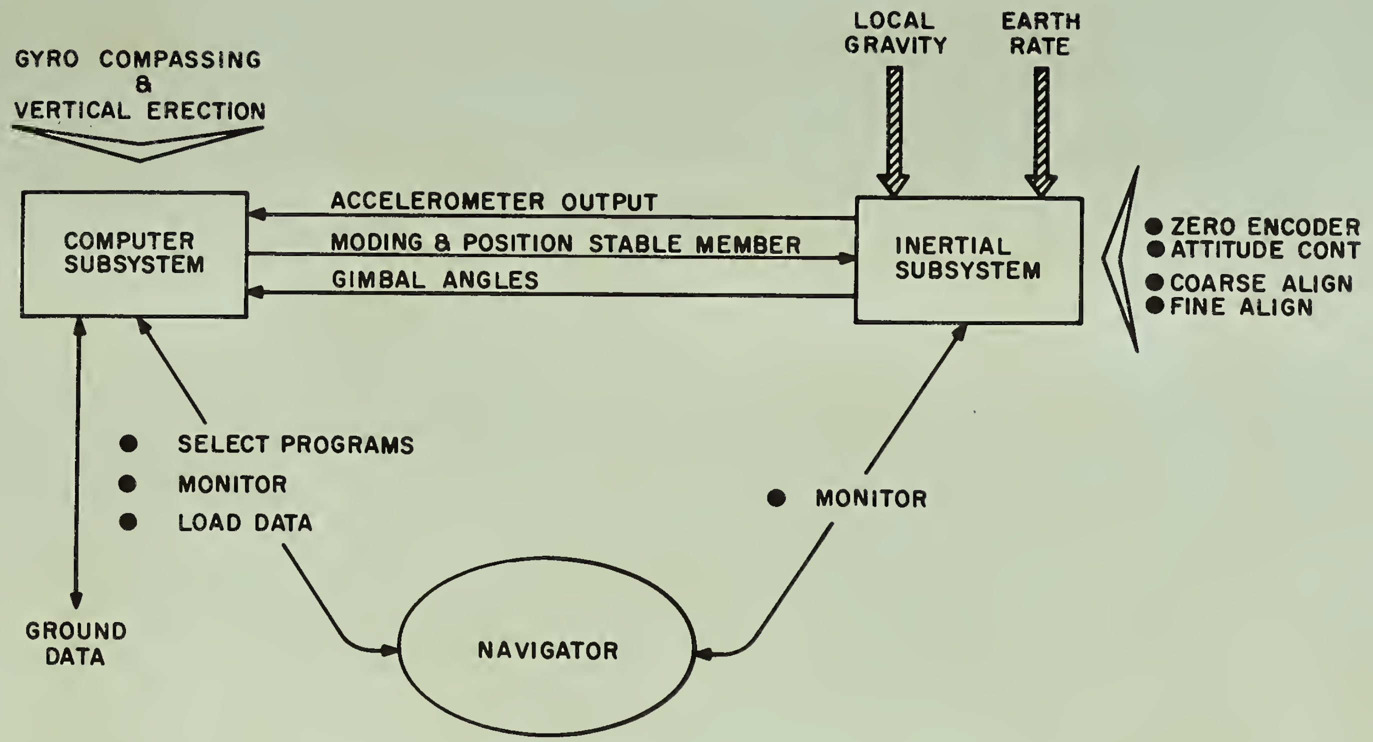


Figure 5-2. Prelaunch IMU Alignment (Simplified G & N System Flow)

The status of the alignment is monitored by the navigator on the DSKY and by the ground station through telemetry and post installation GSE.

5.2 GUIDANCE MONITOR

The purpose of guidance monitor is to monitor the flight profile and mission sequencing during the earth ascent phase and with later systems, the translunar injection phase.

During the S-1B boost period, the computer commands the CDU's to the time history of gimbal angles associated with the nominal S-1B attitude polynominals. The CDU/IMU difference output represents the vehicle attitude errors and is displayed on the FDAI and telemetered to the ground. The FDAI ball will display IMU gimbal angles.

During S-4B boost, the G & N system monitors the IMU gimbal angles to detect tumbling and computes the free fall time to entry interface altitude from present position and velocity.

5.2.1 G & N SYSTEM FLOW. During guidance monitor, inertial and computer subsystems are used with the G & N monitor mode selected on the SCS mode panel (see Figure 5-3). The inertial subsystem, which was aligned during prelaunch is operated in the attitude control mode (monitor S-1B) and the fine align mode (monitor S-4B). The changes in velocity, due to specific forces applied to the spacecraft, and changes in attitude are provided to the computer. The IMU gimbal angles and CDU/IMU difference errors are provided to the FDAI for display. During the attitude control mode the computer issues torquing commands to position the CDU's. Discretes, such as GUIDANCE RELEASE and LIFT OFF, are provided to the computer input from the booster.

5.3 ORBITAL NAVIGATION

When the spacecraft is in orbit about the earth or moon, navigational measurements are taken on predetermined landmarks for updating velocity and position. Due to the high angular rate of the landmark with respect to the spacecraft, the telescope with a large field of view is used for tracking and taking optical measurements.

The landmarks chosen as optical targets during orbital navigation are close to the orbital ground path so that a target image acquired near the horizon is tracked along a path which passes beneath the spacecraft, preferably, not within ±10° of ground track (refer to Figure 5-4).

The orientation of the spacecraft for orbital navigation requires that the optics be pointed toward the earth, with the roll axis (X_{SC}) forward and horizontal and the spacecraft Z axis (Z_{SC}) aligned to local vertical. The stabilization and control system has the capability of providing an automatic orbital rate signal to control spacecraft orientation in SCS local vertical mode and under minimum deadband control.

In preparation for orbital navigation measurements, the navigator installs the rotation control at the navigation station and mounts the optical eyepieces. The IMU must be recently fine aligned to obtain maximum accuracy for orbital navigation measurements. During these measurements, the inertial subsystem is operated in the fine align mode.

The astronaut requests optics power, then selects zero optics mode and verifies that the optics CDU's read zero. With SCS local vertical mode and minimum deadband selected, the navigator refers to the procedures checklist to obtain code number for orbital measurement, which is entered into the DSKY. Then the optics mode switch is set to COMPUTER and the slave telescope switch to STAR LOS. When the landmark code is sent to the computer, the optics shaft and trunnion angles are driven to the required angles. The navigator places the optics in manual resolved mode and centers the landmark in the telescope with the optics hand controller, then presses the mark button. About three equally spaced marks are taken on each target. The CSS

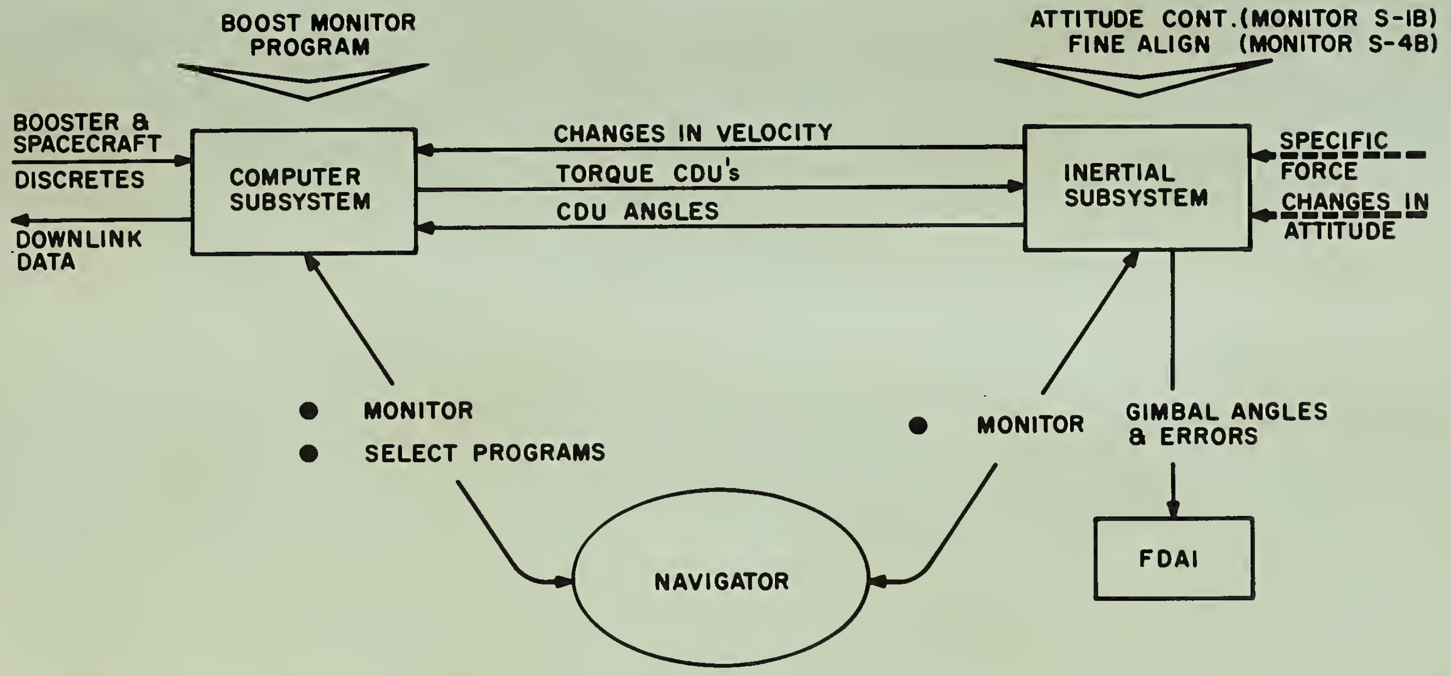


Figure 5-3. Guidance Monitor (Simplified G & N System Flow)

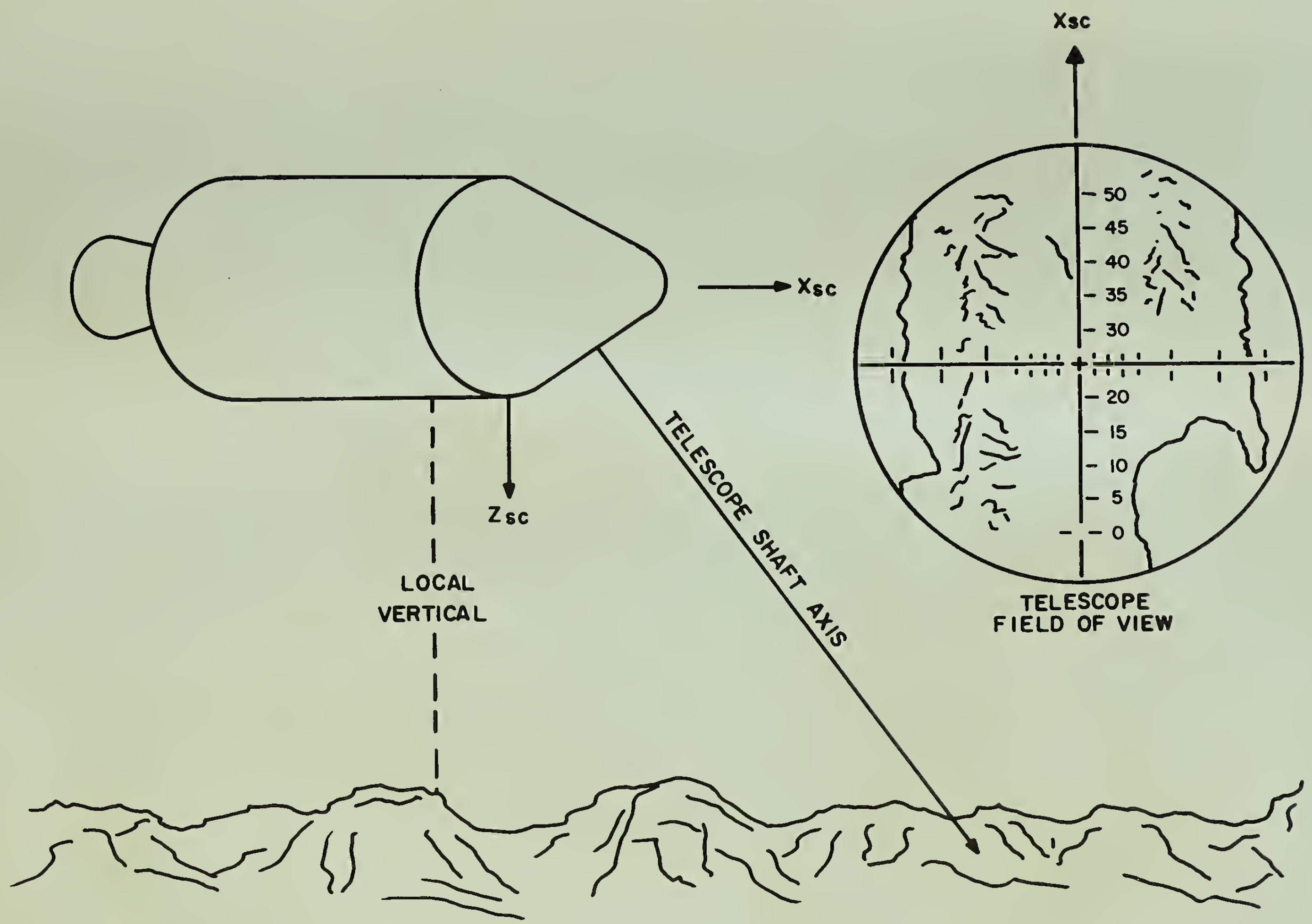


Figure 5-4. Orbital Navigation Sighting

records the optical and inertial CDU angles and the time when the mark button is pressed.

With the inertial subsystem in the fine align mode, the inertial CDU's provide gimbal angle changes to the computer, which calculate the spacecraft orientation with respect to the stable member. The optical CDU's provide changes in the optical angles which define the landmark direction, with respect to the spacecraft. With these two subsystem CDU inputs the computer calculates the landmark direction relative to the stable member.

MSFN receives the position data as the time mark occurs through downlink telemetry. The values are verified by ground computers and relayed to the navigator.

5.3.1 G & N SYSTEM FLOW. During orbital navigation, the inertial, optical and computer subsystems are used and the spacecraft attitude is maintained by the stabilization and control system (see figure 5-5).

The inertial subsystem operates in the fine align mode with the CDU's providing inner, middle and outer gimbal angles to the computer. The optical subsystem is operated in the zero optics, computer and manual mode with the optical CDU's providing shaft and trunnion angles to the computer. The mark command is initiated by the astronaut and issued to the computer by the optical subsystem. The navigator loads data on landmark identification, selects programs and checks position and velocity data obtained from sightings with MSFN.

5.4 INFLIGHT IMU ALIGNMENT

The process of IMU alignment consists of using optical sightings to align the stable member with reference to an inertial frame. The IMU requires alignment each time the inertial subsystem is energized or after a prolonged operation, during which gyro drift could cause an error in stable member alignment. As a general rule, the IMU will be aligned just prior to applying thrust to the spacecraft, prior to making orbit navigation sightings and when the G&N system is used for spacecraft attitude control.

During the alignment process the navigator is located at the lower display and control panel. Basically the alignment procedure consists of two steps, coarse and fine alignment. In the coarse align mode, the stable member is positioned to the approximate orientation. In the fine align mode, the stable member is precisely aligned in the inertial frame.

To accomplish this alignment, the navigator uses the optical telescope and sextant for alignment measurements. The navigator makes the alignment measurements by sighting on two stars for coarse alignment (using the SCT) and again on two stars for fine alignment (using the SXT). When the navigator canters a star in the FOV, he initiates a mark command. Upon this command, the AGC records all CDU settings (inertial and optical) and uses the data to calculate present and required stable member orientation. The optical CDU's contain shaft and trunnion angles (A_s and A_t) required to point the sextant star line-of-sight (star LOS) toward the target star. (See figure 5-6.) Using the measured A_s and A_t, the target star coordinates stored in the AGC are transformed into navigation base axes by AGC programs. The star coordinates are then transformed from navigation base to stable member axes using the measured IMU gimbal angles. The existing stable member star components are compared to a properly aligned stable member to determine the alignment requirements. An intermediate platform orientation may be required to avoid gimbal lock and an intermediate spacecraft orientation may be required to fine align.

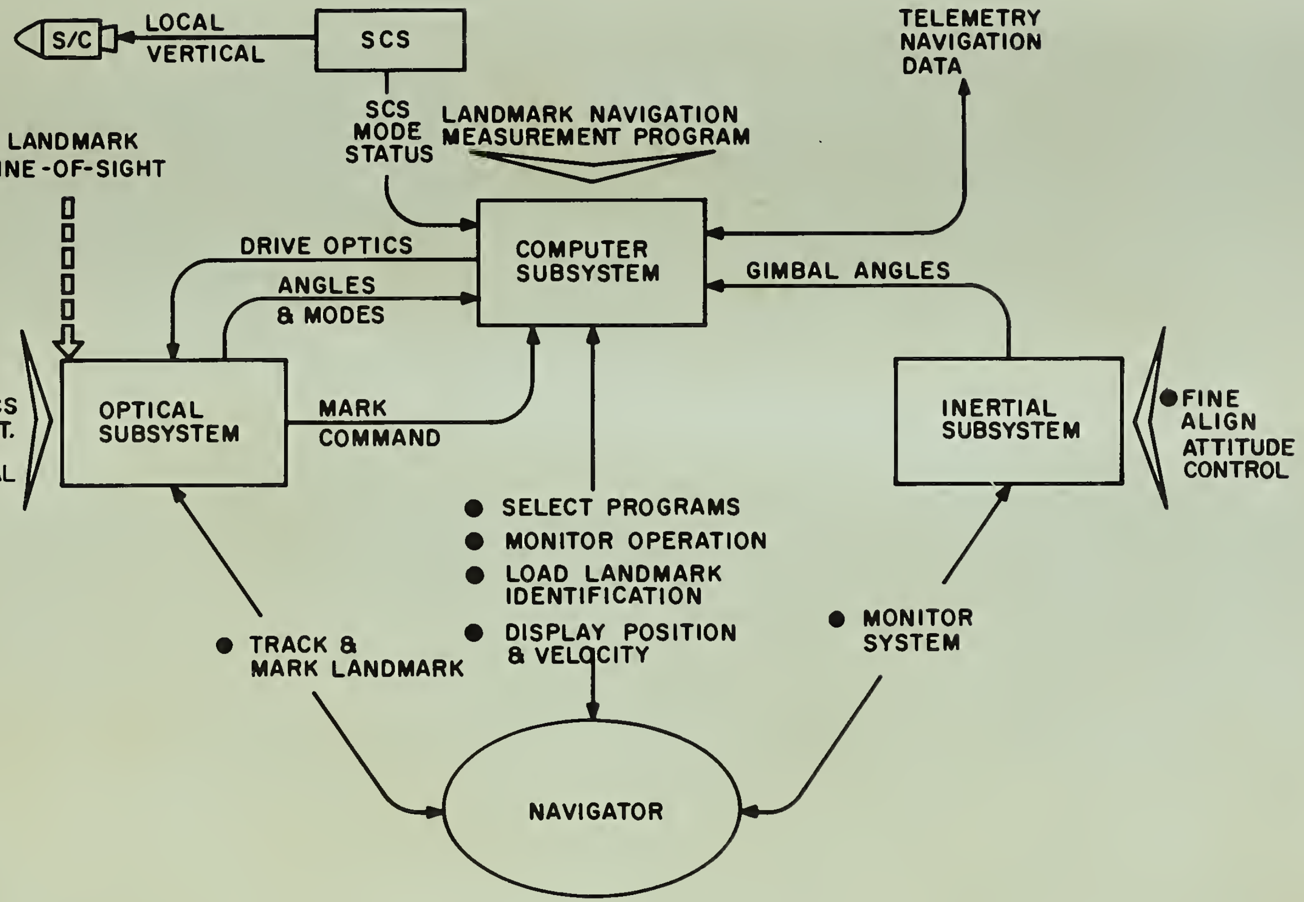


Figure 5-5. Orbital Navigation (Simplified G & N System Flow)

5.4.1 TYPICAL EVENTS FOR AN IMU ALIGNMENT. The basic procedure for IMU align- is described in figure 5-7. The G & N system is prepared for use and type of alignment, initial or update, is determined. If ISS is in stand-by, an initial alignment is required and the system is cycled through coarse and fine align. If the IMU is already aligned but has not been recently realigned, an update alignment may be required. The update alignment requires only the fine align step.

With the initial alignment program selected, the IMU gimbal angles are caged or set to zero and the spacecraft maneuvered, if required, to take the coarse align sightings with the telescope. After the computer has coarse aligned the IMU the spacecraft is again maneuvered to obtain the fine align stars if required. The fine align stars are acquired, the mark command is initiated, and the stable member is torqued into position. A final check of the alignment can be performed by sighting on two additional stars.

If an update alignment is performed, the required computer program is selected and the spacecraft maneuvered into position for taking fine align sightings. Upon completion of sightings, the stable member is torqued into position.

5.4.2 G & N SYSTEM FLOW. All three subsystems are used in aligning the IMU (see figure 5-8). The optical subsystem's zero optics, manual and computer modes are used in taking the sightings. The optical shaft and trunnion angles and mark commands are supplied to the computer. The computer provides drive signals to the optics for positioning the telescope and sextant star lines-of-sight for fine alignment. The inertial subsystem is cycled through zero encoder, coarse align, attitude control and fine align modes to align the IMU. The CDU angles are provided to the computer with the computer issuing commands to the ISS to position the stable member and select ISS modes.

5.5 THRUST MANEUVER

During the Apollo flight to and from the moon thrust maneuvers such as translunar injection, lunar injection, transearth injection and midcourse corrections will be performed. All the maneuvers performed during these phases will result in plane and/or orbital changes.

For the purpose of the Block I (Series 100) study guide the G & N system functions of injection and midcourse correction are combined together as thrust maneuvers. These maneuvers will be used during the Block I (Series 100) flights for near earth, plane and orbital changes. The purpose of a thrust maneuver is to change the velocity and position of the spacecraft, such that, the free-fall trajectory will carry the spacecraft to a required aim point. The thrust is provided by the service propulsion system engines.

5.5.1 G & N SYSTEM FLOW. The computer and inertial subsystems are used in performing a thrust maneuver with the IMU properly aligned for the required thrust maneuver (see figure 5-9). As thrust is applied to the spacecraft, the accelerometer loops provide changes in velocity to the computer which calculates the changing position and velocity. With the ISS in the attitude control mode and the SCS in G & N ΔV, attitude errors are generated which consist of the difference between the IMU and CDU angles. Steering can be performed by the computer by driving the CDU's. If duration of thrusting maneuver is sufficiently long, the

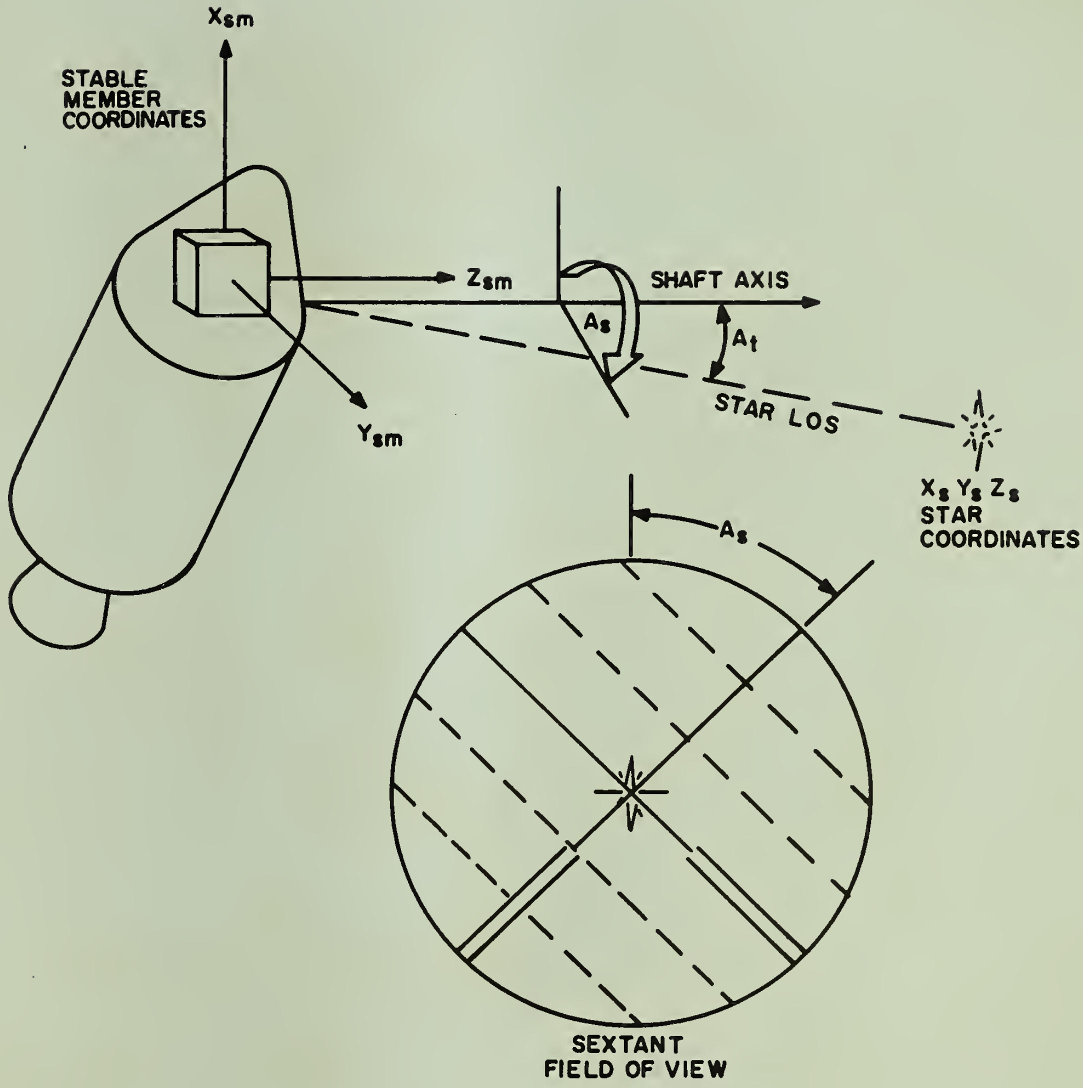


Figure 5-6. IMU Alignment Measurement

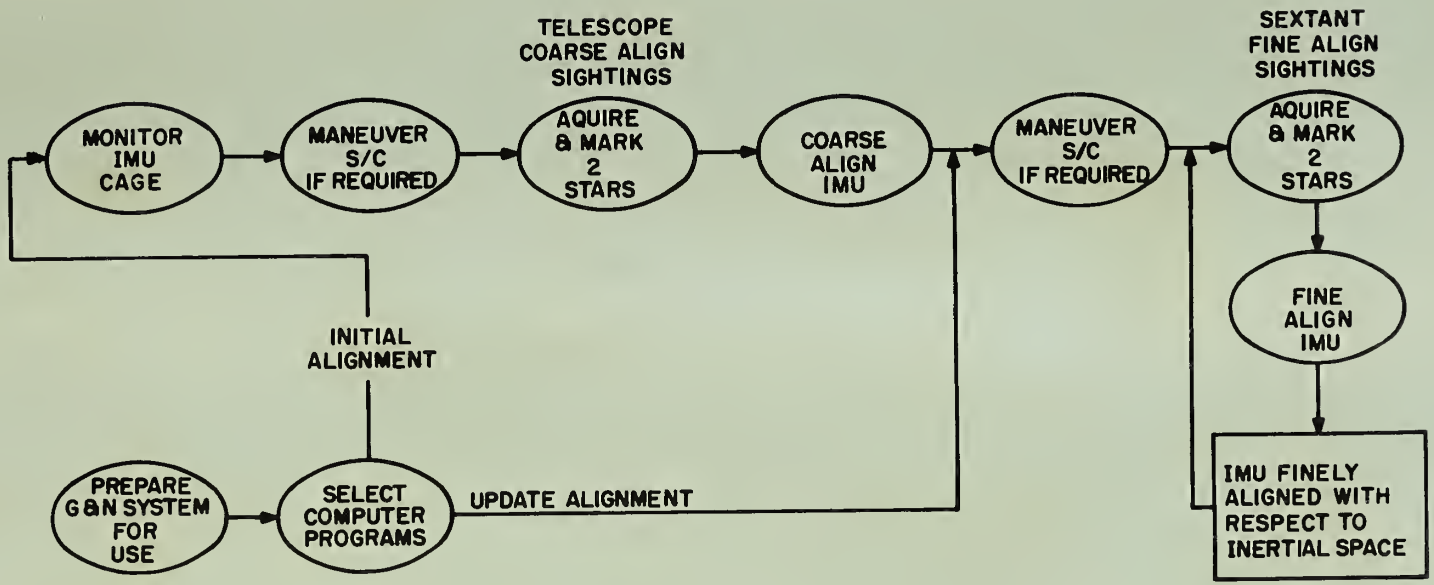


Figure 5-7. IMU Alignment Sequence of Events

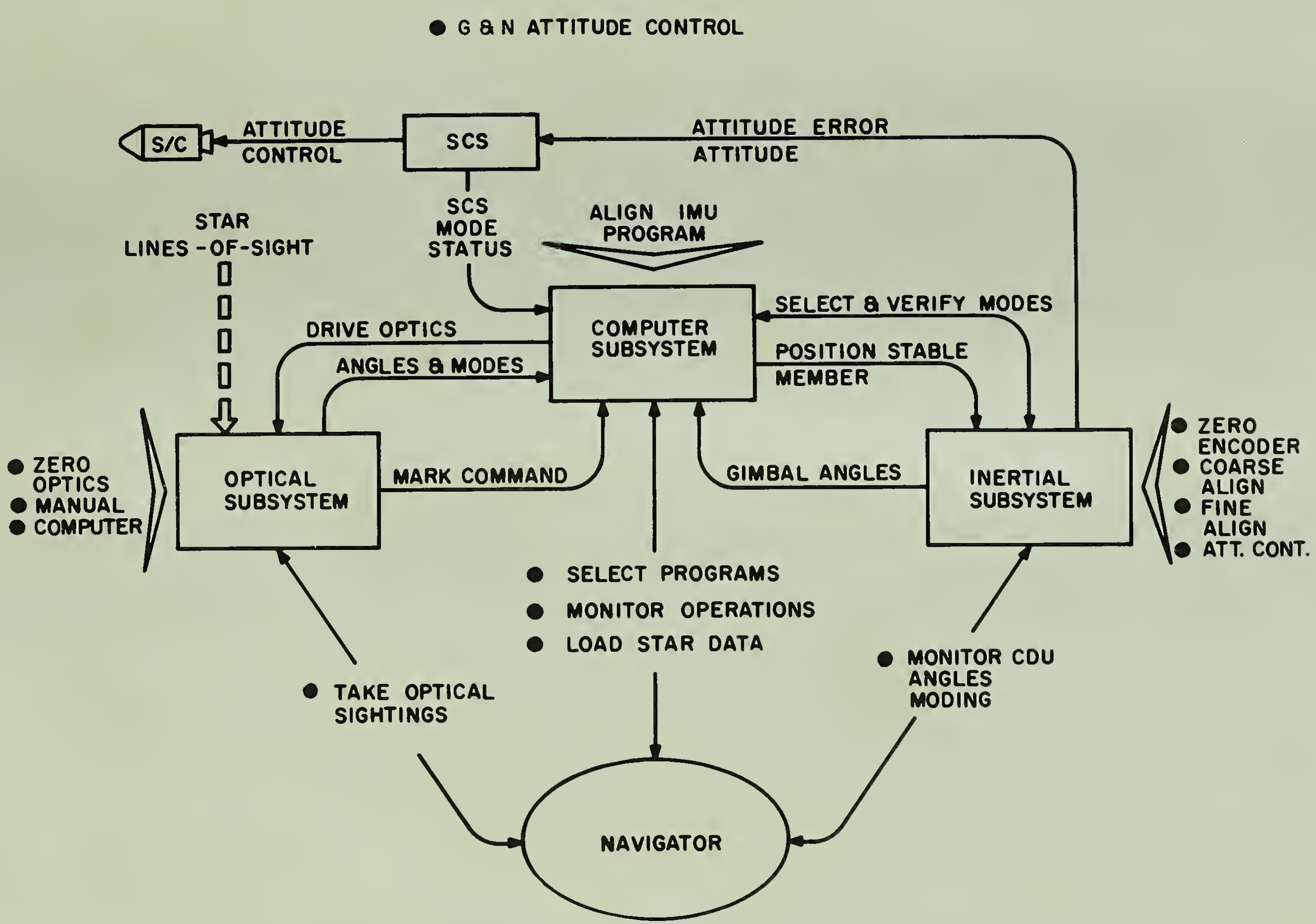


Figure 5-8. IMU Alignment (Simplified G & N System Flow)

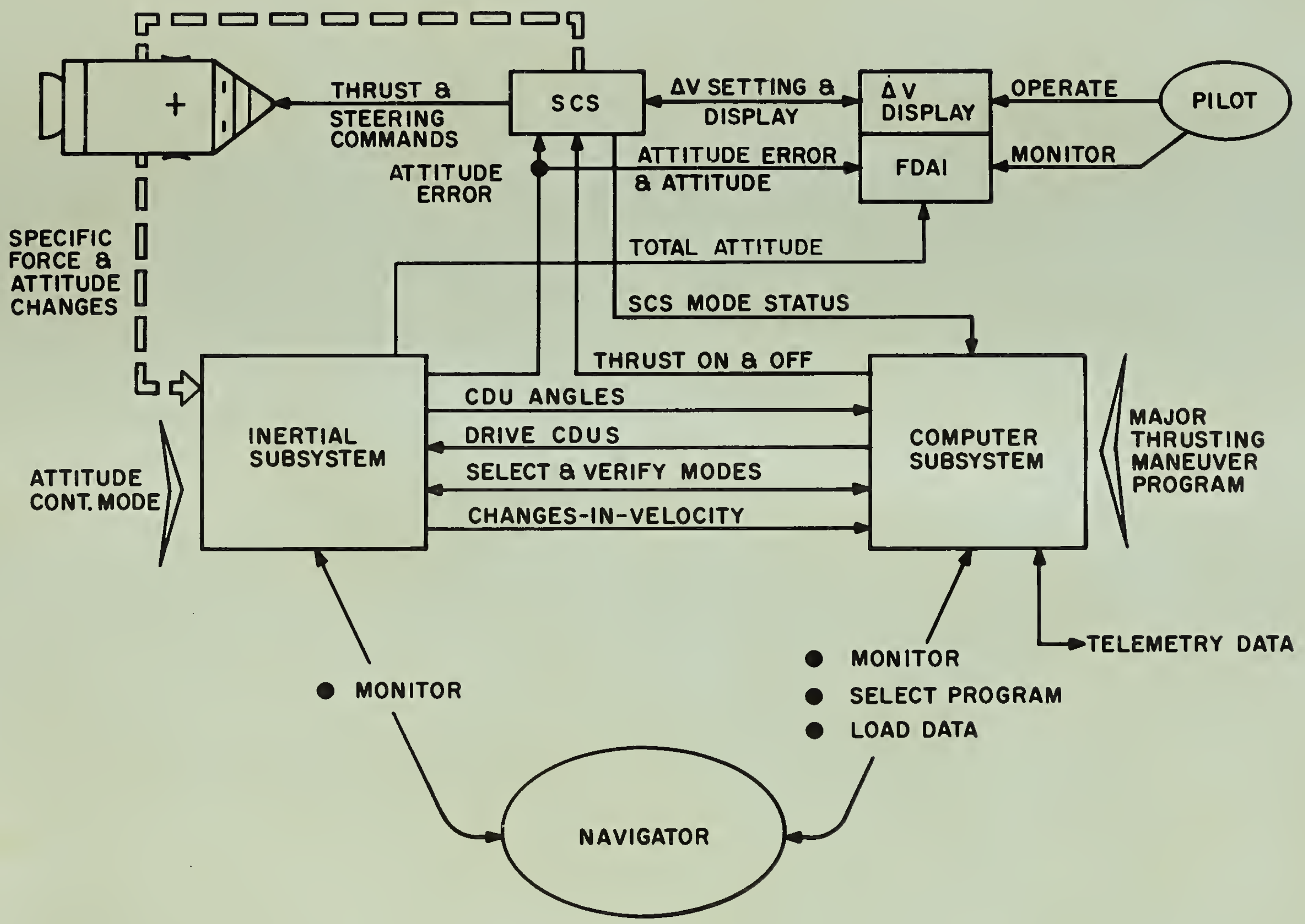


Figure 5-9. Thrusting Maneuver (IMU Alignment Completed)
(Simplified G & N System Flow)

attitude errors and gimbal angles are provided to the FDAI for display to the pilot. Attitude errors are also used for positioning the gimbaled engines.

The computer subsystem issues an on/off discrete to the SCS which ignites the SPS engine. The computer performs the major thrusting maneuver program and requires an input on the center of gravity of the spacecraft. The computer provides the required initial SPS gimbal angle settings to the pilot which are then set into the gimbal position display. An ullage maneuver is performed before the computer issues the thrust command. Upon completion of the maneuver, velocity and position data is displayed and checked with MSFN.

5.6 MIDCOURSE NAVIGATION

A midcourse navigational measurement is accomplished by the navigator operating the sextant to measure the angle between a landmark and a star. It should be pointed out that the navigation sightings are considered as a backup to the MSFN prime navigation system.

The AGC has, in its fixed memory, a catalog of 28 stars stored in a geocentric coordinate system and used as the primary reference for alignment and navigational measurements. The stars are selected for uniform distribution on the celestial sphere so that for a random optical shaft axis direction a reference star is not more than 31 degrees away. Brightness and compatibility with midcourse navigation are also factors in star selection.

The landmarks are outstanding geographic locations on the surface of the earth or moon. The earth landmarks are selected as points of demarkation between land and water that must be clear of cloud cover during the mission.

When the optical angle is obtained during the midcourse navigational measurements a mark command is sent to the computer.

Upon initiating a mark command, the angles between the star and landmark and time of measurement are recorded. The recorded data defines a cone in space (Figure 5-10) with the apex at the landmark. The size of the cone is dependent on the measured angle which is equal to one-half the cone angle. The cone axis is parallel to the star line-of-sight. For any arbitrary point on the surface of the cone, the angle between the landmark and star is the same. Therefore, one sighting defines the spacecraft position somewhere on the surface of the cone. The point on the cone surface nearest the present estimated position becomes an improved estimate of position at the present time.

The spacecraft moves in accordance to dynamic laws. Departure from a reference is sufficiently small to permit linear reduction of the navigation problem by a "running fix" technique. This technique avoids dependence on a reference trajectory. It consists of improving or updating the velocity and position information with each succeeding optical measurement. At the time of translunar injection, there is within the AGC an indication of velocity and position which has been calculated from the inertial subsystem velocity measurements and data on gravitational fields. Solving the equations of motion, the projected position data is obtained by extrapolation and an estimated trajectory is established. Whenever a navigational measurement is taken, the velocity and position information is used in conjunction with the landmark and star coordinates to predict or estimate the angle that should be measured. If the current estimates of position and velocity are correct and there is no instrument error, the measured angle is equal to the predicted angle. If the measured and predicted angles are not equal, the difference is used to update the estimated velocity and position.

The process of taking navigational measurements and converting to linear terms around the present best estimate is a function that is performed throughout the midcourse flight. The velocity and position data is used to determine if a velocity correction is required in order to maintain a satisfactory trajectory.

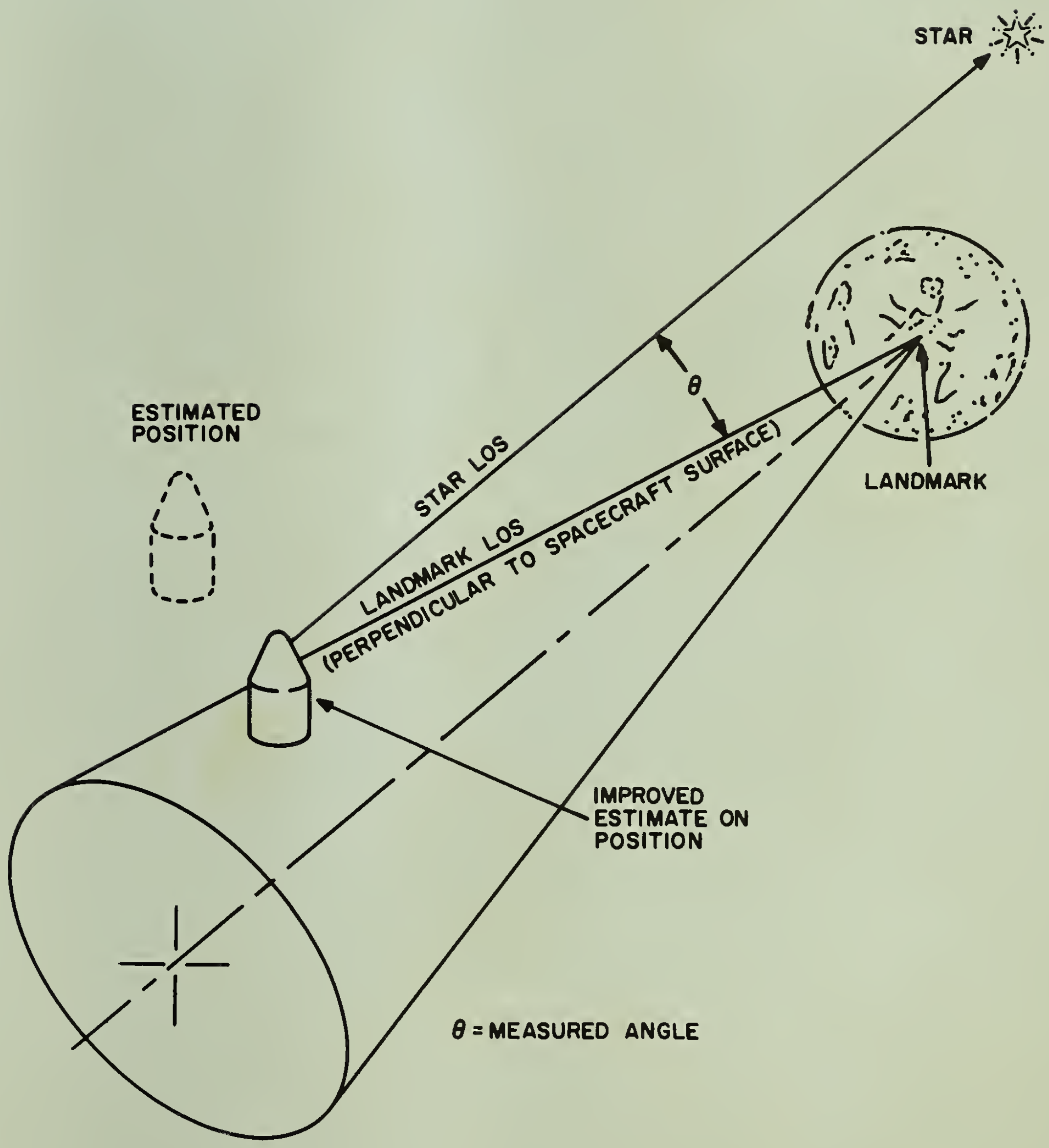


Figure 5-10. Midcourse Position Determination

5.6.1 G & N SYSTEM FLOW. The computer and optical subsystems are used to perform a midcourse navigation measurement with the SCS attitude control mode selected and minimum deadband (see Figure 5-11). The navigator acquires and marks a particular star and landmark using the telescope for coarse acquisition and the sextant for final measurement (see Figure 5-12). Upon initiating a mark command the computer records the shaft and trunnion angles and the time of the sighting. Star and landmark identification is provided to the computer by the navigator. The computer calculates a new estimate of velocity and position which is verified with MSFN.

5.7 ENTRY

About 15 minutes prior to entry the service module is jettisoned and a pre-entry check is performed. Then the command module is pitched approximately 150° to bring the heat shield forward for entry. The command module aerodynamic characteristics are such that as it enters the atmosphere it develops lift and drag. The entry control mode, used during the entry phase, permits the G & N system to control the command module attitude which controls the lift/drag ratio. During the entry program the inertial subsystem is in the entry mode and the SCS is in the G & N entry mode. Lift and drag are varied by rolling the command module about the roll entry axis which parallels the navigation base X axis. As this rotation occurs, the relationship between the command module's aerodynamic center of pressure and center of gravity changes. Aerodynamic moments develop in pitch and yaw to position the command module to a new equilibrium orientation.

Through roll maneuver, lift vector rotation is used for cross range control and downrange control during entry.

The entry "corridor", in which the command module must travel, is the difference between the undershoot or g-limit condition and the overshoot or skip out condition. The overshoot results if the command module does not enter the atmosphere at a steep enough angle. The undershoot is caused by too steep an angle, which results in excessive g-loads. Due to the critical nature of the entry phase, it is necessary that the attitude control loop respond rapidly to an error signal. To achieve this rapid response, roll attitude control is improved by connecting the output of the 1X IMU outer gimbal resolver to the CDU 16X resolver. This connection decreases by a factor of 16 the time required to achieve a desired angle command. This gimbal angle resolver output is proportional to the sine of the angles between the roll gimbal and the spacecraft roll axes. The roll attitude error signal is also the difference between the IMU roll gimbal axis and the CDU roll gimbal axis and the computer can alter it by positioning the roll CDU. The roll error signal output is supplied through an isolation transformer to the SCS where it is used to select the firing of the command module reaction control jets.

The G & N system performance can be monitored by the astronaut through the main panel DSKY.

5.7.1 G & N SYSTEM FLOW. The inertial and computer subsystems are used when performing the entry function with G & N entry mode selected on the SCS mode panel (see Figure 5-13). Changes in velocity and CDU angles are provided to the computer by the inertial subsystem with the computer driving the CDU's and verifying the mode switching. The steering error, consisting of the difference between CDU and IMU angles, is supplied to the SCS to generate roll commands. The attitude error and IMU attitude (gimbal angles) are provided to the FDAI for display.

5.8 ATTITUDE CONTROL

The attitude of the spacecraft is changed frequently during flight for one of the following reasons:

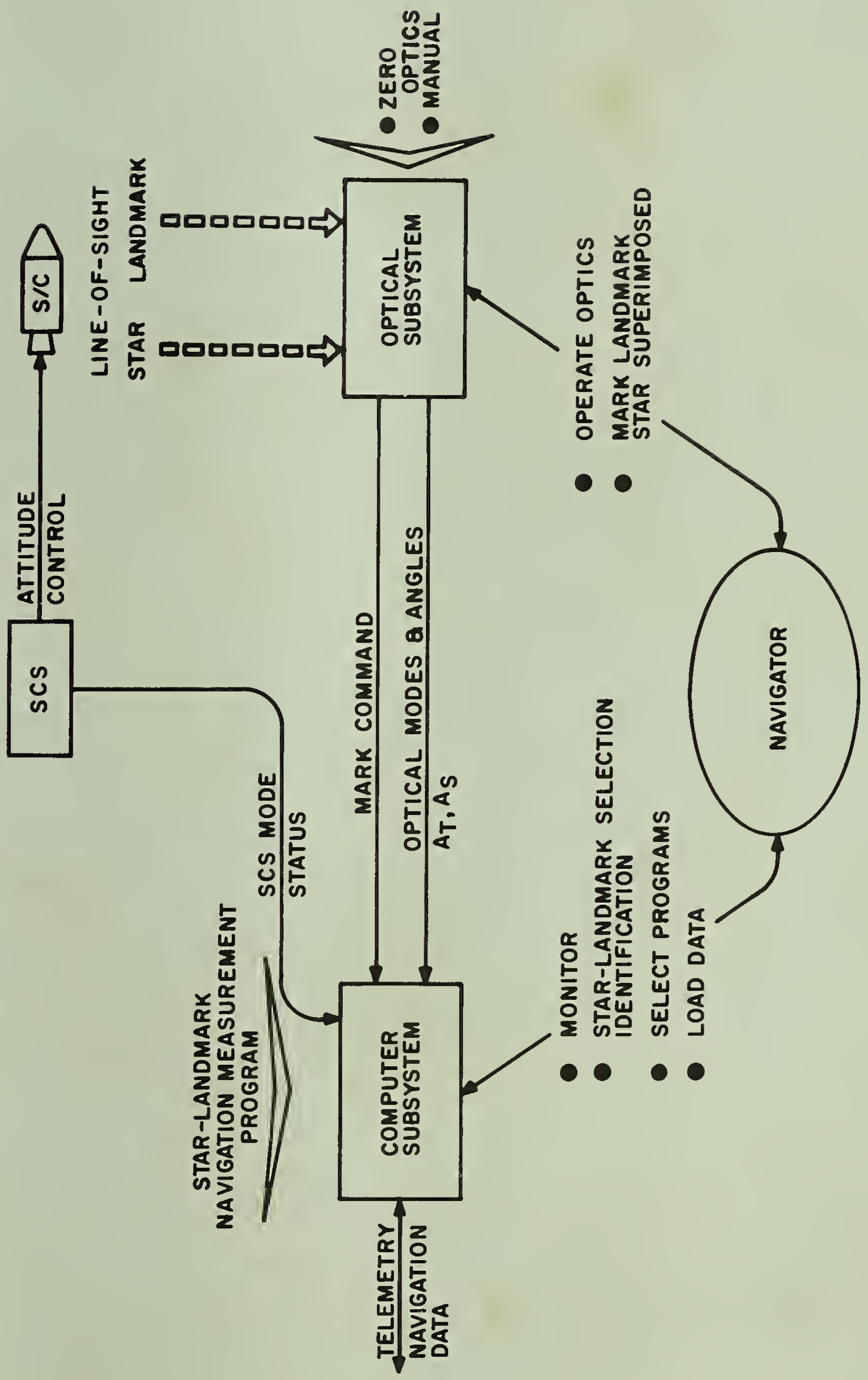


Figure 5-11. Midcourse Navigation (Simplified G & N System Flow)

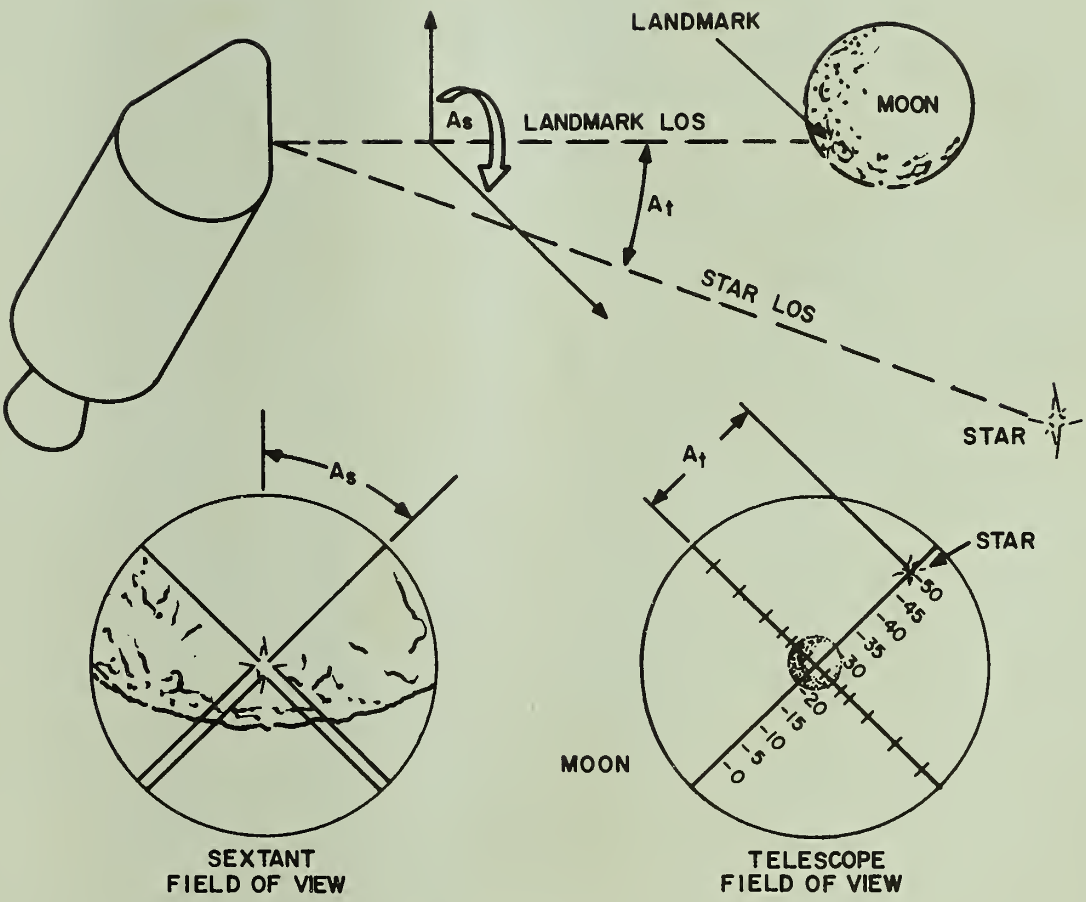


Figure 5-12. Midcourse Navigational Measurement

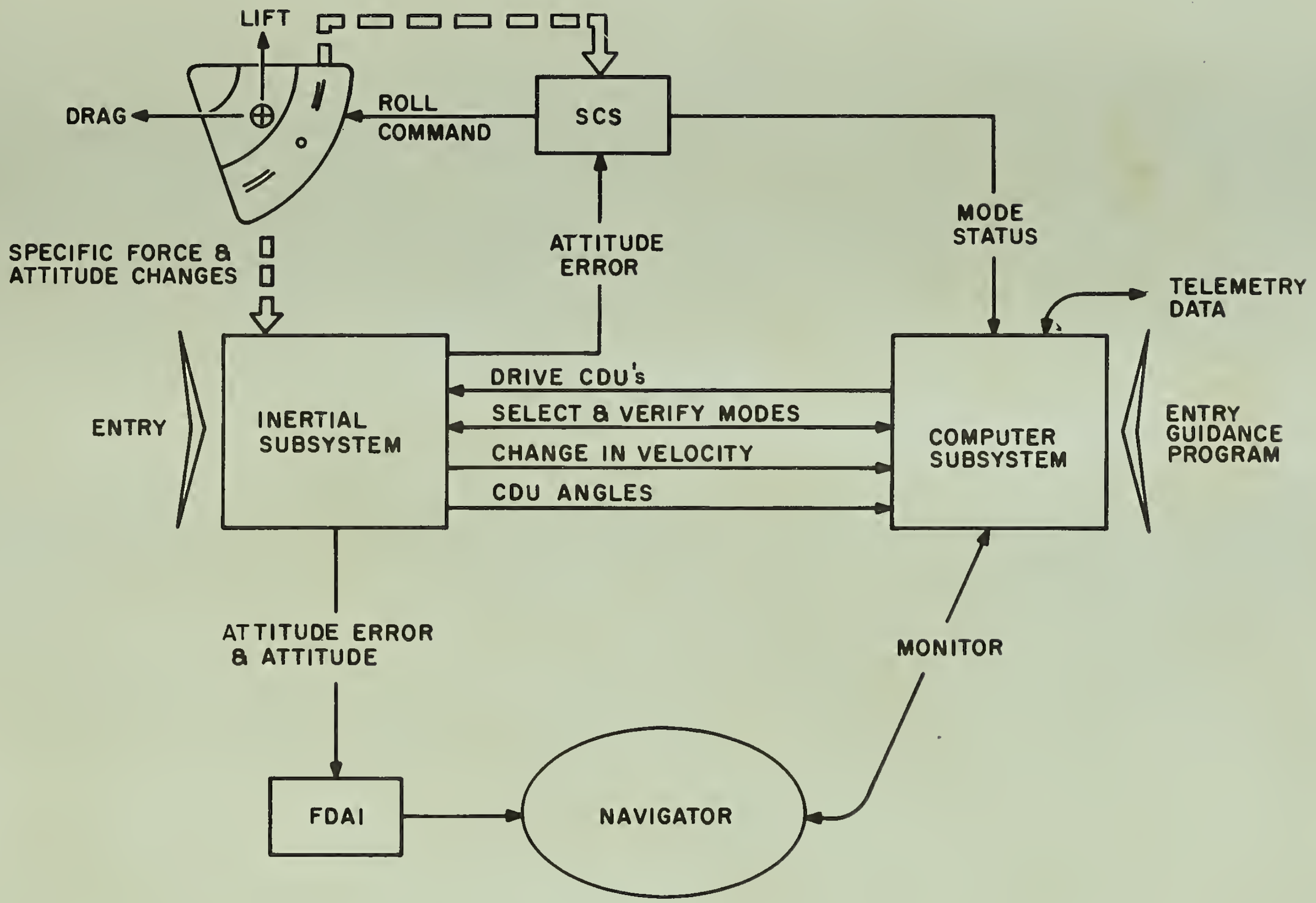


Figure 5-13. Entry (IMU Alignment Completed) (Simplified G & N System Flow)

a. To direct antennas for communications.

b. To change orientation with respect to the sun for thermal controls.

c. To observe celestial bodies.

d. To align spacecraft in preparation for a velocity correction.

The G & N system can generate spacecraft attitude control signals by three methods:

a. Computer control

b. G & N SYNC switch in conjunction with the rotation control

c. Minimum impulse controller

The computer control is used in orienting the spacecraft to a given star field or alignment for thrusting. The G & N SYNC switch is used when the inertial subsystem provides an attitude reference and holds those attitudes selected by the crew with the rotation control. The minimum impulse is used in taking optical sightings to make small changes in the spacecraft rotational rate.

5.8.1 G & N SYSTEM FLOW. The inertial and computer subsystems are used in the attitude control function with the SCS mode of G & N attitude control selected (see Figure 5-14). The CDU's are driven by the computer and the change in the CDU angles are fed back to the computer. The IMU/CDU difference (attitude error) and the IMU gimbal angles are displayed on the FDAI. The mode status of the SCS is provided to the computer. The minimum impulse signal is initiated at the G & N indicator control panel of the inertial subsystem by the navigator.

Since the stable member is gimbaled in three degrees of freedom, the spacecraft maneuvers about the stable member. The gimbal resolvers provide an output proportional to the sine of the angles between the gimbals and the spacecraft. The maneuvering is accomplished by routing the attitude error signal from G & N system through the stabilization and control system to the reaction control system, which turns the control jets (on the command and service module) on and off.

5.9 SUMMARY

The tasks to be performed with the G & N system have been classified into eight basic functions, with each function using a variety of equipment modes. The inertial subsystem excluding the temperature control modes has six equipment modes: zero encoder, coarse align, manual CDU, fine align, attitude control and entry. The optical subsystem has three major equipment modes: zero optics, manual and computer. The computer subsystem is either in standby or operate. The following is a brief summary of each function:

a. Prelaunch IMU alignment: Initial alignment of the IMU in preparation to monitor earth ascent.

b. Guidance monitor: Monitor the earth ascent flight profile and perform abort calculations.

c. Orbit navigation: Update the velocity and position of the spacecraft by tracking landmarks with the optical instruments.

d. Inflight IMU alignment: Align the stable member to provide an inertial reference by taking optical sightings.

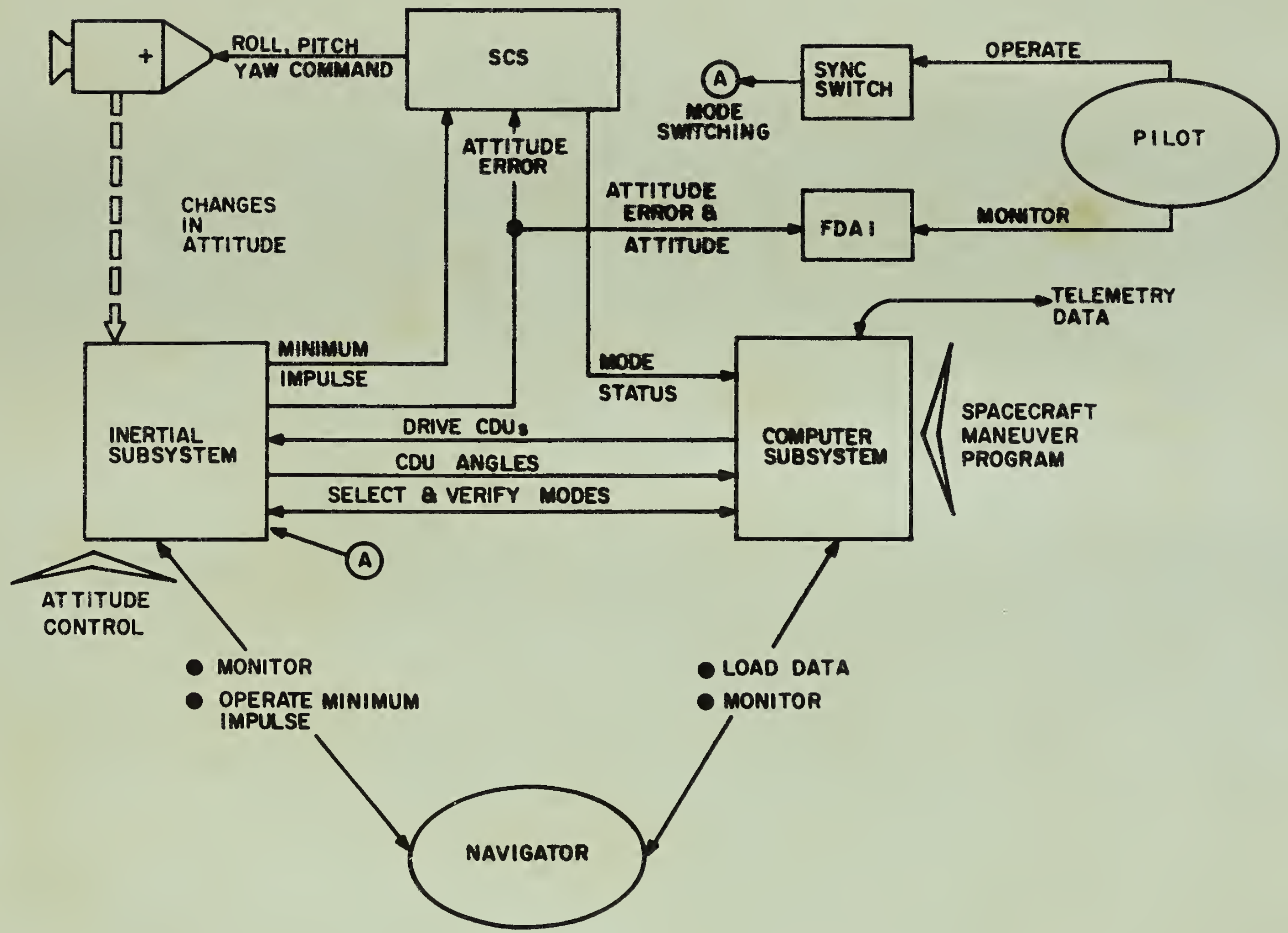


Figure 5-14. Attitude Control (Simplified G & N System Flow)

e. Injection and midcourse correction: Measure and calculate changes in velocity during a thrust maneuver.

f. Midcourse navigation: Update velocity and position data by taking star-landmark measurements.

g. Entry: Measure changes in velocity, solve the guidance problem and issue steering signals to maneuver the command module during the entry phase.

h. Attitude control: Provides the ability to maneuver and hold the spacecraft at a given attitude.

Table 5-1 gives the relationship between the G & N system functions and the G & N system and SCS equipment modes. The equipment modes for each function are not in any particular sequence. The major computer programs per function are also listed. IMU alignment is considered complete upon initiating the orbital navigation, thrusting maneuver, entry and attitude control functions.

Functions \ Equipment Modes	Inertial Subsystem	Optical Subsystem	Computer Subsystem	Possible SCS Mode Selection
Prelaunch IMU Alignment	Zero Encoder Attitude Control Coarse Align Fine Align	Take optical bearing*	Operate Gyro compassing and vertical erection	G & N Monitor
Guidance Monitor	Attitude Control Fine Align		Operate Boost Monitor	G & N Monitor
Orbital Navigation	Fine Align	Zero Optics Computer Manual	Operate Landmark Navigation Measurement	Local Vertical G & N Attitude Control
Inflight IMU Alignment	Zero Encoder Attitude Control Coarse Align Fine Align	Zero Optics Manual Computer	Operate Align IMU Program	SCS Attitude Control G & N Attitude Control
Thrusting Maneuver	Attitude Control		Operate Major Thrusting Maneuver	G & N ΔV
Midcourse Navigation		Zero Optics Manual	Operate Star-Landmark Navigation Measurement	SCS Attitude Control
Entry	Entry		Operate Entry Guidance	G & N Entry
Attitude Control	Attitude Control		Operate Attitude Maneuver	G & N Attitude Control SCS Attitude Control

Table 5-1. Relationship of Functions to Equipment Modes

REVIEW QUESTIONS FOR SECTION V

T F 1. The IMU must be aligned when performing the midcourse navigation function in order to determine the spacecraft velocity and position.

T F 2. The accelerometer outputs are used during prelaunch IMU alignment to determine if the stable member axes are properly aligned.

T F 3. Fine alignment is a closed-loop operation with the CDU outputs supplied to the computer and used to determine when the stable member is properly aligned.

T F 4. The IMU must be aligned during orbit navigation.

T F 5. The computer can drive the optical instruments to a field of stars.

T F 6. The minimum impulse controller is used during a thrust maneuver to position the SPS engines.

T F 7. The gyros located on the stable member are continuously being torqued when the fine align mode indicator is on.

T F 8. The computer subsystem issues an on/off discrete to the SPS engine causing the engine to gimbal.

T F 9. The inertial subsystem is on and aligned during all thrust maneuvers.

T F 10. A ullage maneuver is performed before the computer issues the thrust command.

G & N SYSTEM TESTING & CHECKOUT

INTRODUCTION

This section briefly discusses:

a. Preinstallation testing and checkout philosophy.

b. The ground support equipment (GSE) necessary for G & N system testing and checkout.

c. The G & N system tests.

6.1 TESTING AND CHECKOUT PHILOSOPHY

The testing and checkout philosophy for the Apollo G & N system features a continuous pattern of testing procedures from subsystem acceptance test through countdown and in-flight monitoring by telemetry. The level of testing decreases at each station as the assemblies are combined into subsystems, subsystems into a system, and the system is installed into the spacecraft and moved to the launch pad. The key tests are repeated at each station, thus establishing continuity of test records.

The development, design, verification, evaluation, qualification, and reliability testing of the guidance and navigation subsystems and system is divided according to the objectives of the G & N system contractor and the spacecraft contractor. The objective of G & N contractor testing is to check the operation, qualification and reliability of the G & N system. The objective of the spacecraft contractor test program is to insure the operational integrity of the G & N system with the spacecraft and other spacecraft systems.

In the G & N system contractor test plan, the inertial, optical, and computer subsystems are checked out or tested as individual subsystems, married into a complete G & N system, and checked out and tested again. Three configurations of test stations provide a test and checkout capability for the G & N system and its subsystems. An ISS/OSS test station is utilized for ISS and/or OSS checkout, a G & N test station is utilized for G & N system testing and a universal test station (UTS) provides an all-system test capability. The UTS is described in Section 6.4. The test stations are composed of checkout consoles, recording equipment, rotary tables, holding fixtures and various support equipment.

The spacecraft contractor test plan evaluates, in three phases, the G & N system over-all compatibility with the total Apollo spacecraft. The first phase confirms procurement specification requirements and assures proper G & N system operation using a mockup of the actual command module cabling. The second phase checks the interface between the G & N system and the stabilization control system. During the third phase, the G & N system is installed in the spacecraft and checked out as a part of the complete spacecraft system.

6.2 GSE FUNCTIONS

The GSE accomplishes six major functions:

a. Supplies prime power to the G & N subsystems.

b. Supplies coolant to the subsystems.

c. Provides stimuli for subsystem tests.

d. Monitors and indicates subsystem functions.

e. Maintains and monitors temperature of inertial components (except when on airborne control.

f. Provides transportation and storage for airborne equipment.

6.3 GSE COMPONENTS

The major GSE components necessary to check out the G & N system are:

a. Optics - inertial analyzer.

b. Oscillograph console.

c. Coolant and power console.

d. Computer test set.

e. G & N mounting fixture.

f. Overhead junction box.

These components are briefly discussed in the following paragraphs.

6.3.1 OPTICS-INERTIAL ANALYZER (OIA). The optics-inertial analyzer is a four bay console used during the G & N system tests to check out the ISS and OSS components. The OIA provides stimuli and control signals to the OSS and ISS. It also monitors and measures signals from the OSS and ISS. It also monitors and measures signals from the OSS and ISS and can route various signals to the oscillograph console for permanent recording. The OIA also maintains temperature control of the inertial components and provides continuous monitoring of the temperature. (See Figure 6-1)

6.3.2 OSCILLOGRAPH CONSOLE. The oscillograph console is a single bay console used to make permanent records of signals selected by the OIA. It also provides a remote readout of the counter located in the OIA. (See Figure 6.1)

6.3.3 COOLANT AND POWER CONSOLE. The coolant and power console is a two bay console which performs three major functions during G & N system testing and checkout (See Figure 6.1):

a. Supplies prime power to the airborne equipment.

b. Provides cooling to the airborne equipment.

c. Provides for monitoring of precision voltages from the airborne equipment.

6.3.4 COMPUTER TEST SET (CTS). The CTS is a two bay console which can be used to evaluate the dynamic operation of the AGC. The CTS automatically or manually simulates conditions encountered by the AGC, evaluates AGC responses to these conditions and tests the integral AGC circuits required to generate proper responses. (See Figure 6.2)

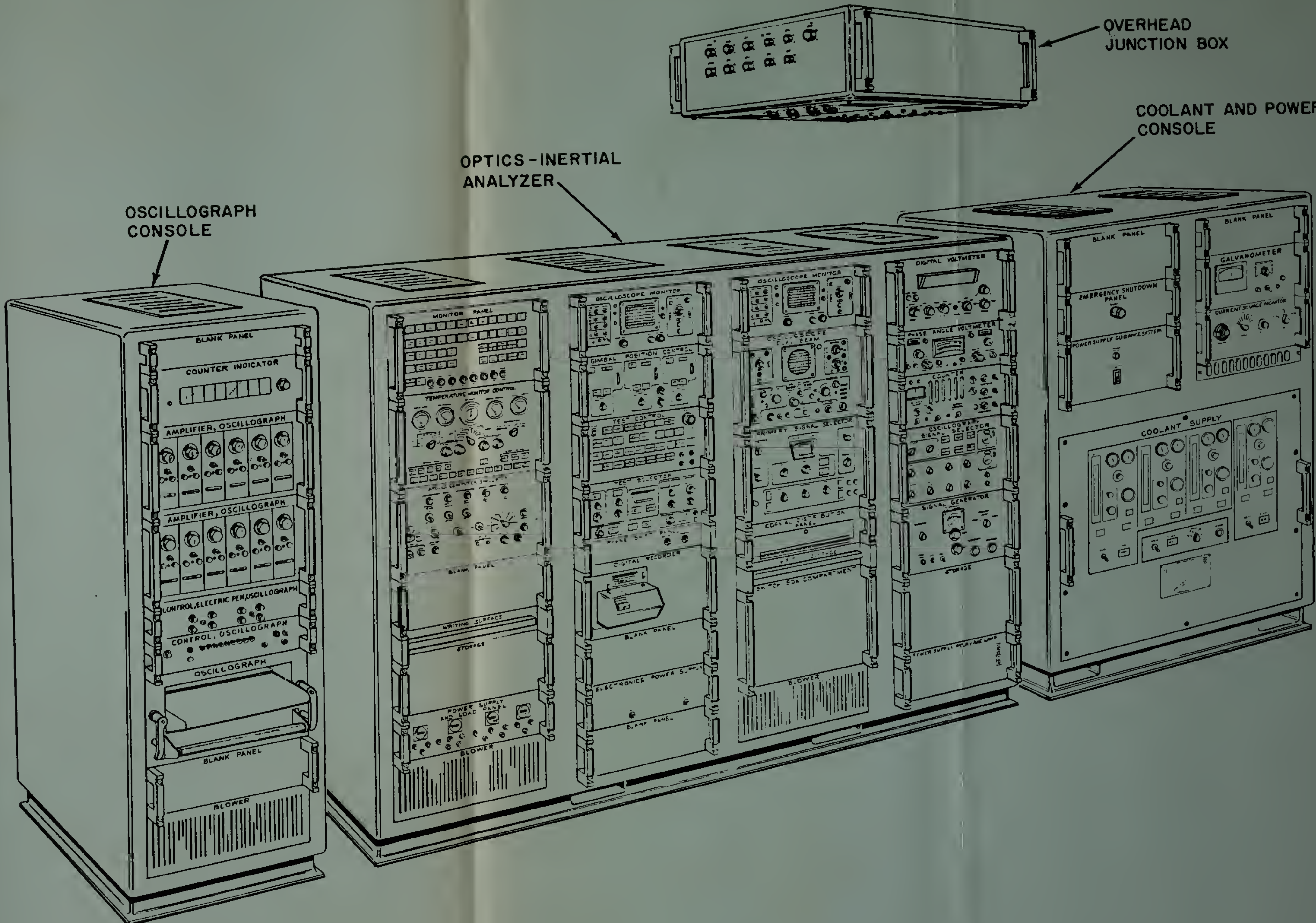


Figure 6-1. Optics-Inertial Test Set

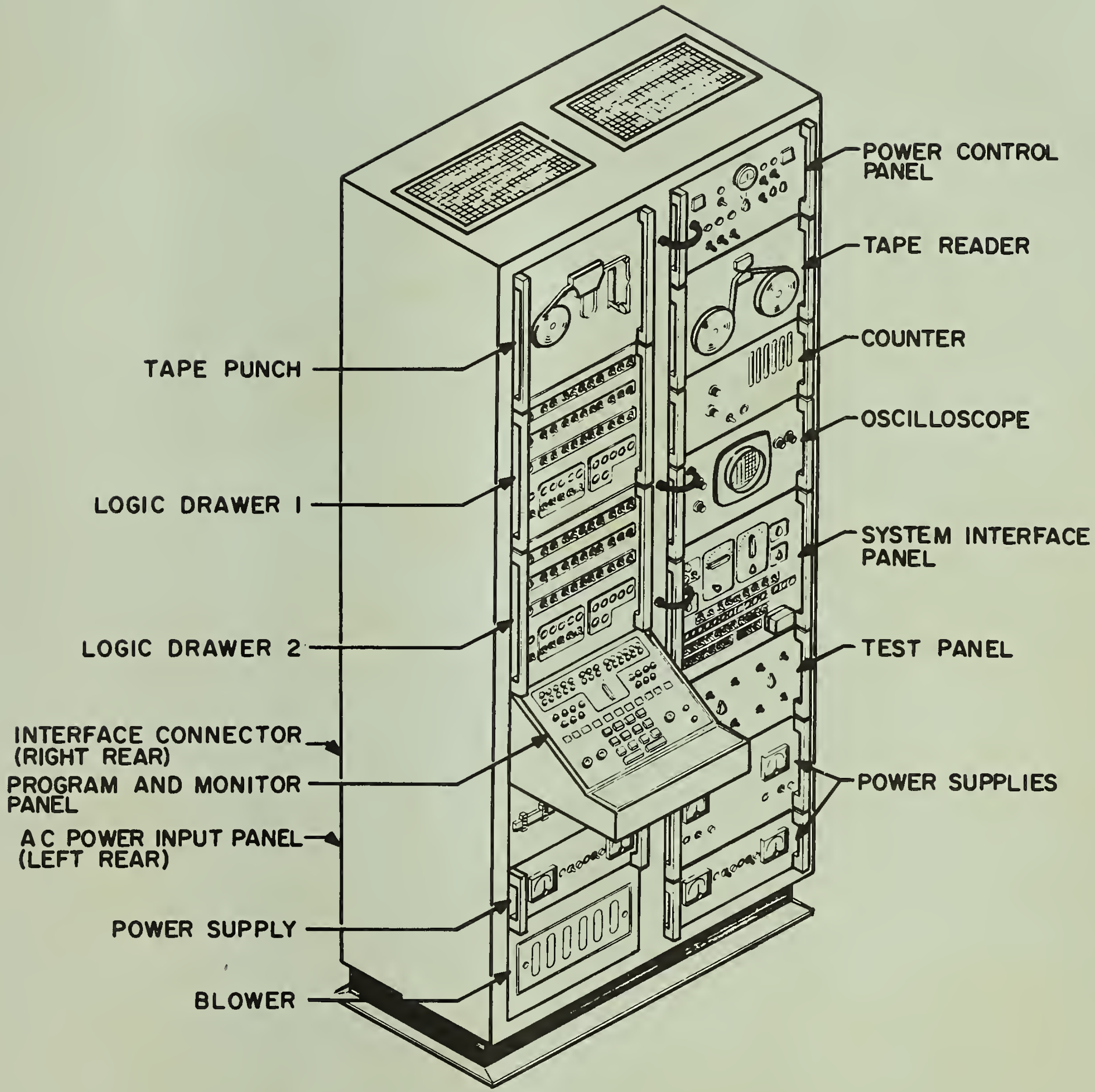


Figure 6-2. Computer Test Set Console

6.3.5 G & N MOUNTING FIXTURE. The G & N mounting fixture holds all of the G & N system equipment except the main panel DSKY during system checkout. (See figure 6-3). In addition to the airborne components, the G & N mounting fixture also holds:

a. Coldplates used to remove heat from the various temperature controlled components.

b. Plumbing which circulates the cooling solution from the coldplates.

The G & N mounting fixture is capable of tilting the airborne equipment approximately 32.5 degrees in one direction and 90 degrees in the opposite direction.

6.3.6 OVERHEAD JUNCTION BOX. The overhead junction box provides the interconnect and switching between the airborne components and the GSE. (See figure 6-1.)

6.4 UNIVERSAL TEST STATION

A universal test station is used at the system assembly and test (SAT) contractor's facility (AC Electronics) and at all field sites. A typical universal test station is illustrated in figure 6-4. The universal test station consists of the CTS, the OIA, an oscillograph console, a coolant and power console, a work bench, and optical targets grouped around a G & N mounting fixture and a rotary table.

This test station can be used for individual subsystem checkout as well as G & N system checkout. When an inertial subsystem is being checked, the IMU, PSA, and a GSE/PSA junction box are mounted on holding fixtures, which in turn are mounted on the rotary table. The other airborne components are mounted on the G & N mounting fixture. When an optical subsystem is being checked, the navigation base-optics assembly is mounted on a holding fixture which is mounted on the rotary table. The other airborne components are mounted on the G & N mounting fixture. All airborne components except the main panel DSKY are mounted on the G & N mounting fixture during G & N system checks.

6.5 SYSTEM TEST SEQUENCE DESCRIPTION

Upon arrival of subsystems at MIT/IL, AC Electronics, NAA and MILA, the individual subsystems undergo a receiving inspection check to determine the physical condition of the equipment, to note discrepancies, and to review the equipment configuration. After checkout of the individual subsystems has been completed, the optical, inertial and computer subsystems are mounted on the G & N mounting fixture and the following G & N functional tests conducted (not necessarily the order listed):

a. Power supply checks.

b. Temperature control check.

c. AGC check.

d. IMU mode control check.

e. Optics control mode check.

f. Accelerometer loop checks.

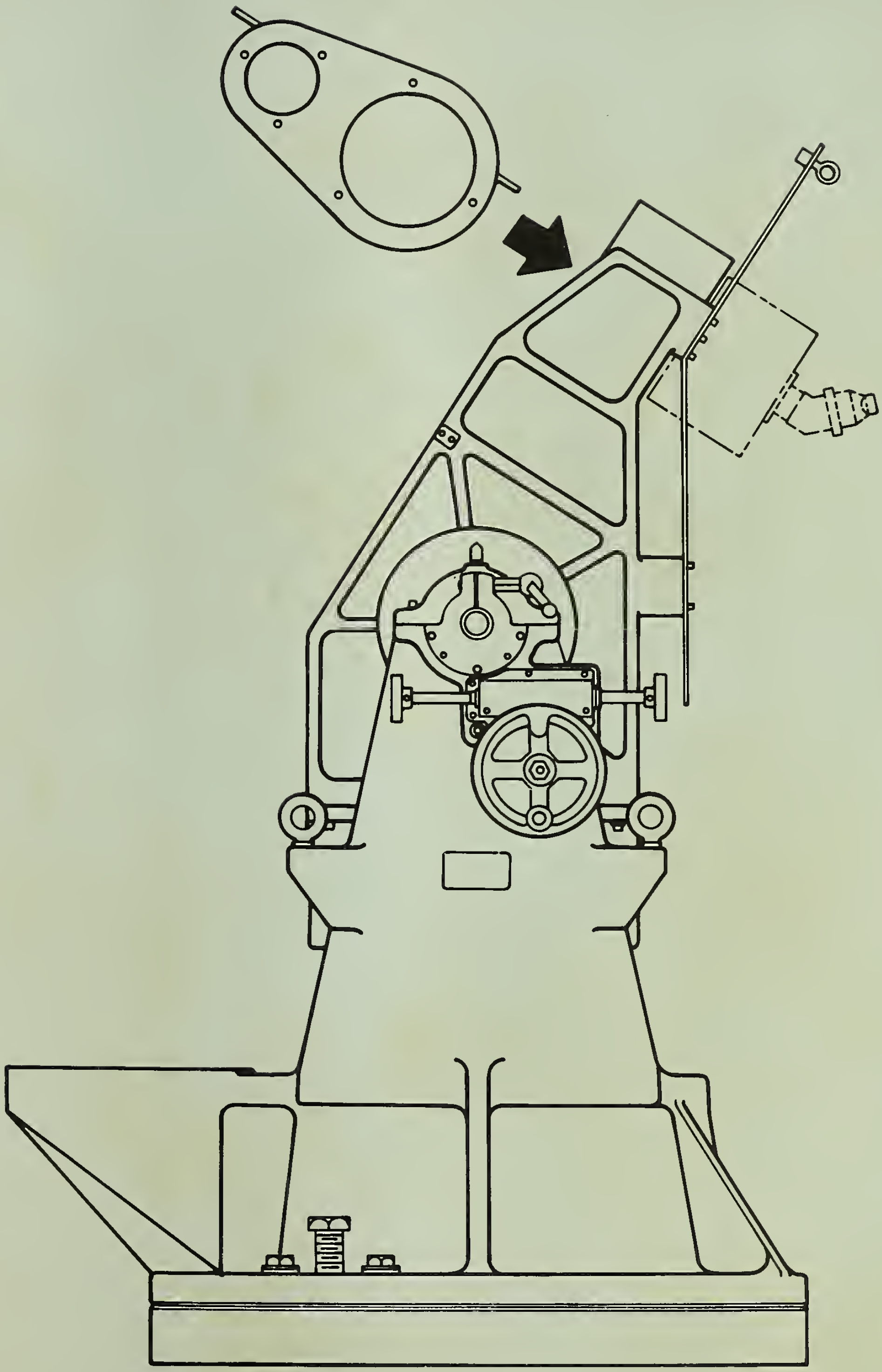


Figure 6-3. G & N Mounting Fixture

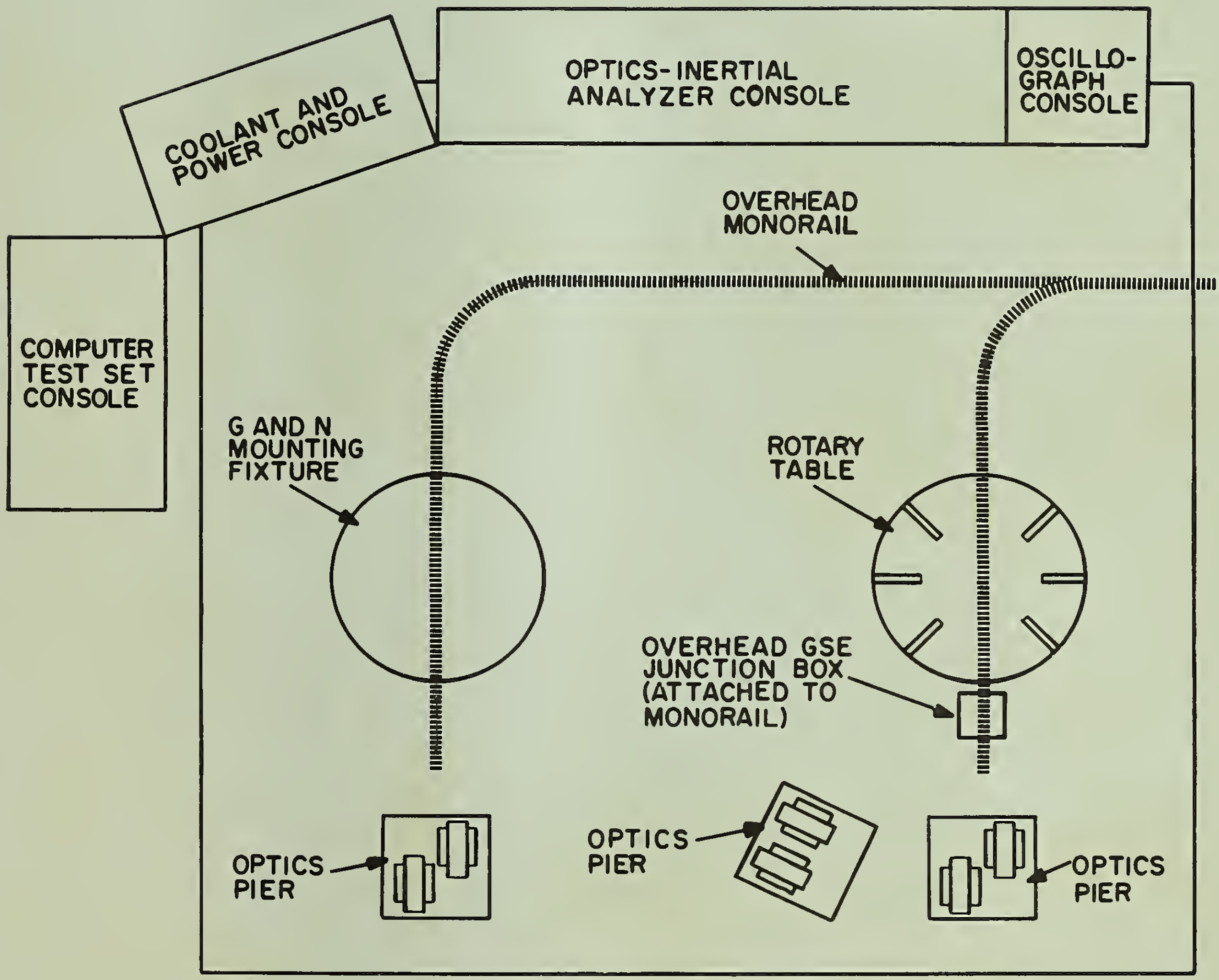


Figure 6-4. Typical Universal Test Station

g. Stabilization loop checks.

h. Gyro compassing check.

i. Positional loop check.

j. Optics slew check.

k. Gimbal slew check.

l. System fine alignment accuracy check.

m. Optics positional accuracy check.

n. Interface checks.

o. Display and control checks.

6.5.1 POWER SUPPLY CHECKS. The outputs of the power supplies of the G & N system are measured to determine if they meet specifications.

6.5.2 TEMPERATURE CONTROL CHECK. The characteristics of the temperature control loops are tested to verify that the loops are functioning properly. With the inertial subsystem in the operate mode of operation, the duty cycle of the temperature control loops is checked when the temperature control system is in the backup and emergency modes. The temperature stability is checked in the proportional, backup, and emergency modes. The duty cycle of the heater and blower currents is determined with the inertial subsystem in the coarse align mode.

With the temperature indicating loops in the auto-override mode, gain and balance is checked by pressing the 25 IRIG gain button on the G & N indicator control panel which causes the IMU temperature lamp on the condition annunciator panel to light. The 25 IRIG and heater current telemetry outputs indicate that the switchover to the emergency mode of operation has occurred. The same check is conducted using the 16 PIP gain button and telemetry outputs.

6.5.3 AGC CHECK. Before the AGC is connected to the AGE harness interface, a computer self-check is accomplished. The AGC performs a program that exercises the fixed memory circuits, erasable memory circuits, central and special registers, the AGC alarm circuitry and the DSKY's. The AGC alarm circuitry and the DSKY's are also manually exercised.

6.5.4 IMU MODE CONTROL CHECK. This check consists of exercising the IMU modes of operation automatically by the AGC and manually. As the system is advanced through the following IMU modes of operation, the following characteristics are checked to verify proper moding.

6.5.4.1 <u>IMU Turn-On</u>. The IMU delay lamp lights and then goes out after a 40 second delay. The IMU CDU's are checked for a null indication during the coarse align mode. The AGC mode register is checked for the proper mode indication.

6.5.4.2 <u>Zero Encoder Mode.</u> The zero encoder lamp lights and the IMU CDU's are checked for a zero reading. The AGC mode register is checked for the proper mode indication and the CDU counters in the AGC are checked for zero.

6.5.4.3 Coarse Align Mode. The coarse align lamp lights and the angle difference between the IMU gimbals and their respective CDU's is checked on the IMU-CDU difference meter and the CDU 1X resolver nulls. The AGC mode register is checked for the proper moding indication.

6.5.4.4 CDU Manual Mode. The manual CDU lamp lights and the digital to analog converter inhibit is checked. The AGC mode register is checked for the proper mode indication.

6.5.4.5 Manual Align Mode. With the CDU manual and manual align switches actuated, the manual CDU lamp lights and the digital to analog converter inhibit is checked. The AGC mode register is checked for the proper mode indication and the IMU CDU difference meters are checked for a null.

6.5.4.6 Fine Align Mode. The fine align lamp lights, the AGC mode register is checked for the proper mode indication and the 16X CDU resolver nulls are checked.

6.5.4.7 Attitude Control Mode. The attitude control mode lamp lights and the AGC mode register indicates that proper moding has occurred. The CDU's are displaced from the IMU angle and the angular difference is checked on the IMU-CDU difference meter.

6.5.4.8 Entry Mode. The entry mode lamp lights and the AGC mode register indicates that proper moding has occurred.

6.5.5 OPTICS CONTROL MODE CHECK. When the zero optics mode is commanded, the optics CDU's, AGC mode register and AGC angle counters are checked for proper zero optics mode indications. The AGC mode register is checked for the proper mode indication when the optics are in the manual mode of operation.

In the resolved mode of operation, the telescope image motion is checked to determine if the image motion is up-down or left-right for a given optics hand controller position. The image movement rate is timed to check if it remains at a constant rate for an initial shaft angle of 225 degrees and various trunnion angles.

When the slave telescope switch is in the star LOS position, the ability of the telescope trunnion angles to repeat the sextant trunnion angles at 0 degrees and 25 degrees is checked. When the slave telescope switch is in the offset 25 degree position, the telescope trunnion is checked for a 25 degree offset. When the switch is in the landmark LOS position, the telescope trunnion is checked for a zero degree indication and position.

6.5.6 ACCELEROMETER LOOP CHECKS. The accelerometer loop checks consist of scale factor and bias tests. To check accelerometer scale factors and bias, the IMU is fine aligned in positions that hold the input axis of each 16 PIP parallel to local gravity in order to apply a 1g input to the 16 PIP. Each 16 PIP is checked twice, once with its positive input axis up and again with it down.

6.5.7 STABILIZATION LOOP CHECKS. A constant peak-to-peak voltage of various frequencies is applied to each gimbal torque drive amplifier to determine the frequency response of each stabilization loop. Also, the 25 IRIG coefficient tests are conducted by allowing one gimbal to drift while holding the other two gimbals in the fine align mode. The stable platform is positioned at various known orientations with respect to gravity and earth rate. These orientations are chosen so that two accelerometers will not sense a gravity input at the start of the test. Rotations of the drifting gimbal due to gyro unbalances and earth rate are measured by the two accelerometers. IRIG bias drift (BD), drift due to acceleration along the IRIG input axis (ADIA) and drift due to acceleration along the IRIG spin reference axis (ADSRA) are determined through a computer controlled test. The BD and ADSRA terms are derived by using the east PIPA as a sensor. The average ADIA terms are derived by using the outer gimbal CDU as a sensor. The 25 IRIG pulse torque scale factor is also determined as well as the gimbal friction level.

6.5.8 GYRO COMPASSING CHECK. During the gyro compassing check, the stable platform is leveled and maintained in azimuth so that the Y and Z 16 PIP's sense no gravity input and the Z IRIG is pointing toward the desired azimuth. After a period of time which is required for stabilization, the capability of the AGC to hold the stable platform in this position is checked.

6.5.9 POSITIONAL LOOP CHECK. This check determines the time required for the IMU and optics CDU's to zero. The five digital to analog converters are checked with respect to positional accuracy and response.

6.5.10 OPTICS SLEW CHECK. The tachometer of each optical CDU is monitored when the CDU's are slewed at high, medium, and low rates to determine proper image rates and tracking capability.

6.5.11 GIMBAL SLEW CHECK. A check of the maximum rate at which the IMU gimbals move when they are slewed is performed.

6.5.12 SYSTEM FINE ALIGNMENT ACCURACY CHECK. The purpose of this test is to check the ability of the G & N system to fine align the stable member utilizing a special fine alignment AGC program. Three different orientations of the stable member are used. In each orientation, two 16 PIP's are leveled so that they sense no gravity input. The fine alignment is checked by using the output rate of the two leveled 16 PIP s, if any, to calculate the alignment error. The stable member axes are initially aligned with respect to an optical reference.

6.5.13 OPTICS POSITIONAL ACCURACY CHECK. The accuracy of the angle between the sextant landmark LOS and star LOS is checked. The parallelism between the sextant landmark LOS and star LOS is also checked. Also, the accuracy of the telescope trunnion LOS is demonstrated.

6.5.14 INTERFACE CHECKS. There are three groups of interface signals that are checked; (a) telemetry, (b) PSA front panel, and (c) spacecraft. All simulated inputs to these groups and outputs from these groups are checked. The telemetry group includes all signals associated with uplink, downlink and central timing equipment. The PSA front panel group includes all signals associated with ACE carry-on equipment and external IMU temperature control. The spacecraft group includes all signals interfacing with other spacecraft systems and the main display and control panel.

6.5.15 DISPLAY AND CONTROLS CHECK. The purpose of this test is to verify the operation of the various condition and status indicators and the coolant lamps. To check the individual condition lamps on the condition annunciator panel, various malfunctions are simulated. The capability of varying the brightness of the panel lamps is checked. The IMU mode lamps and the optics tracker button are checked by pressing the check mode lamps button. The AGC failure lamps are checked by pressing the test alarm button and the condition lamps are checked by pressing the check condition lamps button. The coolant lamps are checked to see if the area in which the IMU coolant quick disconnects are located can be illuminated by pressing the check coolant button.

6.6 SUMMARY

The six major Apollo GSE functions are:

a. Providing prime power for the G & N system.

b. Providing cooling of the system.

c. Initiating subsystem tests.

d. Monitoring and indicating subsystem functions.

e. Maintaining temperature of the inertial components.

f. Providing transportation and storage for the G & N system equipment.

The G & N system is checked out and tested at MIT/IL, AC Electronics, NAA and MILA. At AC Electronics, the test area is designated the systems assembly and test (SAT) area and at MIT/IL, NAA and MILA the test areas are designated G & N labs. Within each test area is a universal test station which is used for G & N subsystem and system checkout. The major GSE components utilized during G & N system checkout are:

a. Optics inertial analyzer (OIA).

b. Oscillograph console.

c. Coolant and power console.

d. Computer test set (CTS).

e. G & N mounting fixture.

f. Overhead junction box (OJB).

The OIA controls, monitors, and measures OSS and ISS tests. Various signals can also be routed through the OIA to the oscillograph console for permanent recording. The coolant and power console supplies prime power and coolant fluid to the G & N equipment. It also has the capability of monitoring precision voltages from the G & N system. The CTS is used during G & N testing to evaluate AGC responses to certain conditions. The G & N mounting fixture is used to hold and position the G & N system equipment. The OJB provides the interconnects and switching necessary between the GSE and the G & N system. During G & N testing and checkout the system is checked to insure that it can perform properly.

REVIEW QUESTIONS FOR SECTION VI

1. List the six major GSE functions.

   a.

   b.

   c.

   d.

   e.

   f.

2. List the six major GSE components used during G & N system testing.

   a.

   b.

   c.

   d.

   e.

   f.

3. In what major areas are the universal test stations located?

APPENDIX

ANSWERS TO SECTION I REVIEW QUESTIONS

1. a. Optical navigation - see paragraph 1.3.3

   b. Inertial guidance - see paragraph 1.3.2

2. a. EPS - see paragraph 1.2.1.4

   b. ECS - see paragraph 1.2.1.5

   c. SCS - see paragraph 1.2.1.1

   d. RCS - see paragraph 1.2.1.3

   e. SPS - see paragraph 1.2.1.2

   f. C&IS - see paragraph 1.2.1.6

3. a. Navigation base (NB)

   b. Optical unit

   c. Inertial measurement unit (IMU)

   d. Coupling display units (CDU's)

   e. Power and servo assembly (PSA)

   f. Apollo guidance computer (AGC)

   g. Display and control panels

4. a. Inertial subsystem (ISS)

   b. Optical subsystem (OSS)

   c. Computer subsystem (CSS)

ANSWERS TO SECTION II REVIEW QUESTIONS

1. The two basic functions of the ISS are: (a) attitude control and (b) velocity measurements.

2. The IMU gimbal angles are transferred to the AGC through the three ISS CDU's.

3. The stable member is stabilized through the use of 25 IRIG stabilization gyros.

4. During coarse align, the IMU platform is positioned by the IMU gimbal servo motors via the CDU's. The CDU's develop the error signal to drive the gimbal servo motors.

5. During fine align, the AGC provides the torquing signals to torque the IRIG's. The IRIG's then develop the error signal to drive the IMU gimbal servo motors.

6. During attitude control, the IMU maintains the attitude reference and the CDU's develop the steering signals which are routed to the SCS for attitude steering.

7. The auto-override IMU temperature control mode maintains the IMU temperature and automatically switches from a proportional type control to the emergency control if a malfunction occurs in the proportional control circuitry.

8. The navigation base X and Z axes are displaced 33 degrees back from the spacecraft X and Z axes, while the navigation base Y axis and spacecraft Y axis are parallel. While the IMU gimbal angles are zero, the outer gimbal axis is parallel to the X_{nb} axis, the inner gimbal axis is parallel to the Y_{nb} axis and the middle gimbal axis is parallel to the Z_{nb} axis.

ANSWERS TO SECTION III REVIEW QUESTIONS

1. T

2. T

3. F

4. T

5. T

6. F

7. F

8. The function of the zero optics mode is to drive the CDU's, sextant and telescope to a zero reference position and clear the optics encoder counter in the AGC.

9. Sextant

10. The hand controller error signals are resolved from polar to rectangular coordinates and the shaft drive signal is reduced when the sextant trunnion angle is large.

ANSWERS TO SECTION IV REVIEW QUESTIONS

1. a. Apollo guidance computer (AGC)

   b. Main panel DSKY

   c. Navigation panel DSKY

2. DSKY

3. T

4. T

5. T

6. T

7. Time shared

8. KEYRUPT

9. A T3 RUPT is caused by the overflow of the TIME 3 counter and is used to schedule time dependent tasks.

10. a. Controls DSKY relays

    b. Samples ISS and OSS modes

    c. Sets up conditions for positioning the OSS and ISS

    d. Samples failure indications

    e. Checks downlink telemetry rate

    NOTE: Any two of the above answers

ANSWERS TO SECTION V REVIEW QUESTIONS

1. F

2. T

3. F

4. T

5. T

6. F

7. F

8. F

9. T

10. T

ANSWERS TO SECTION VI REVIEW QUESTIONS

1. a. Supply prime power to the G & N subsystem

   b. Supply coolant to the G & N subsystem

   c. Initiate system and subsystem tests

   d. Monitor and indicate subsystem functions

   e. Maintain temperature of the inertial components

   f. Provide transportation and storage for the G & N system components

2. a. Optics-inertial analyzer

   b. Oscillograph console

   c. Coolant and power console

   d. Computer test set

   e. G & N mounting fixture

   f. Overhead junction box

3. Systems assembly and test (SAT) area and G & N lab

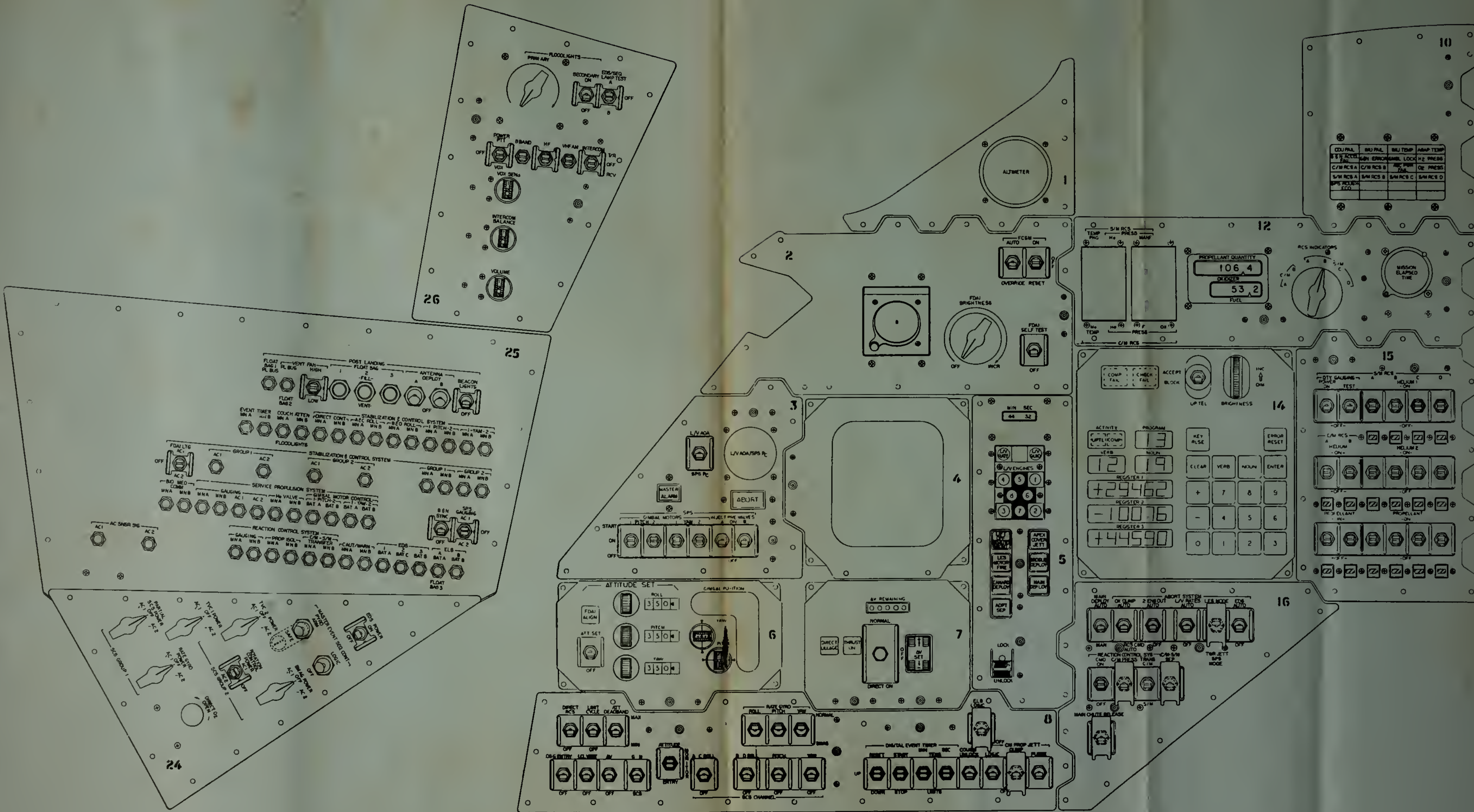


Figure A-1. Block I (Series 100) Main D & C (Sheet 1 of 2)

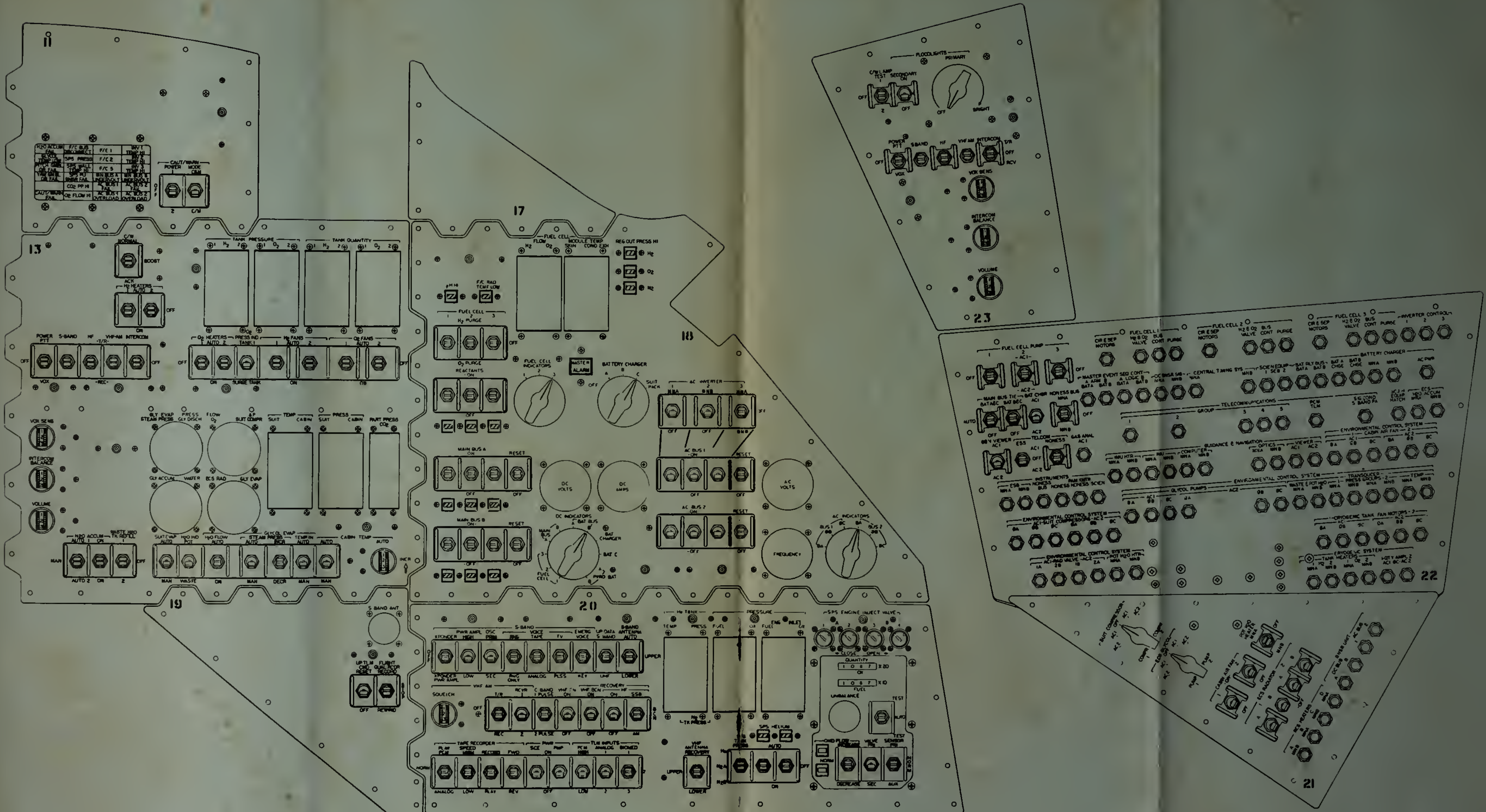


Figure A-1. Block I (Series 100) Main D & C (Sheet 2 of 2)

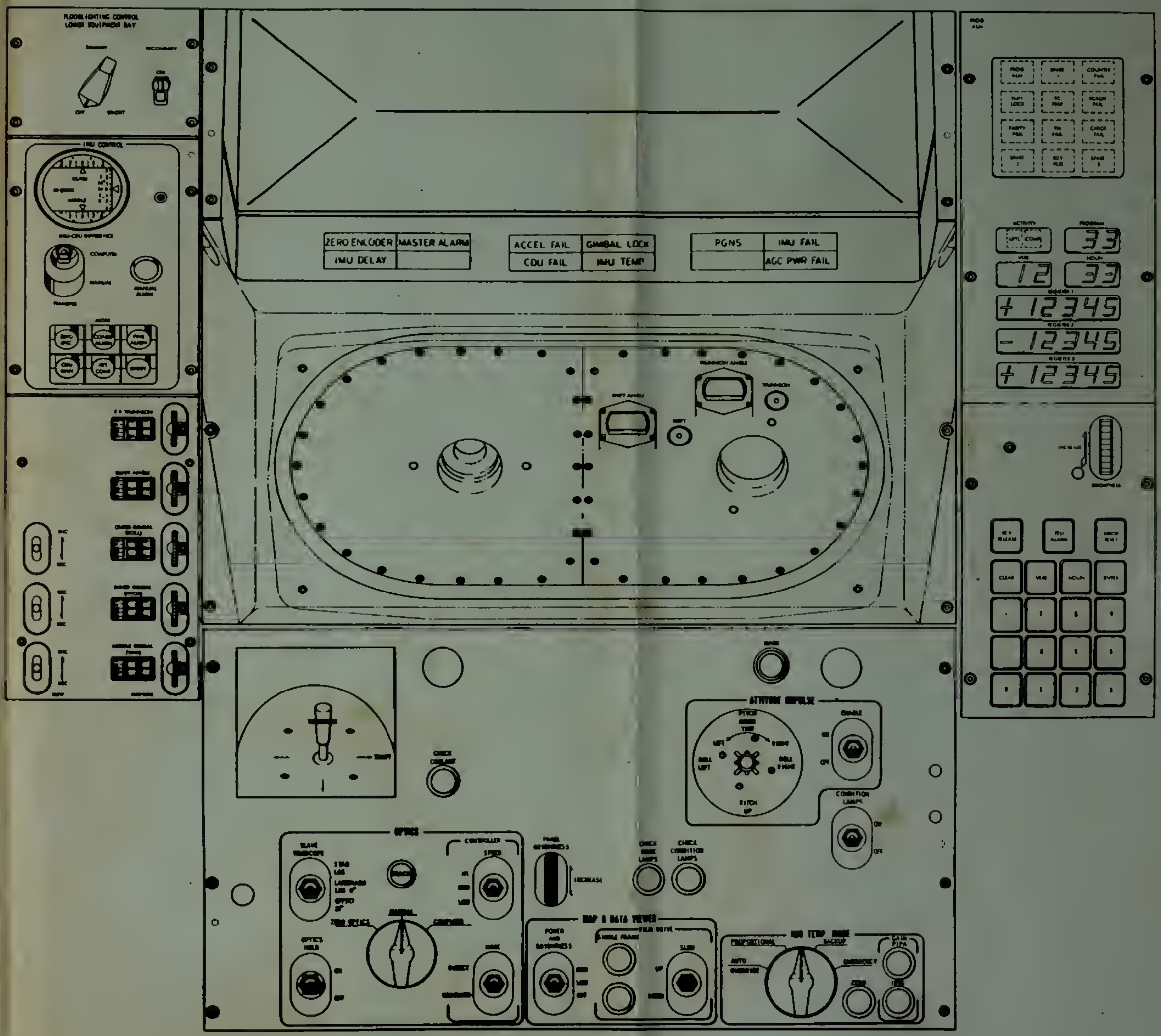


Figure A-2. Block I (Series 100) Lower D & C

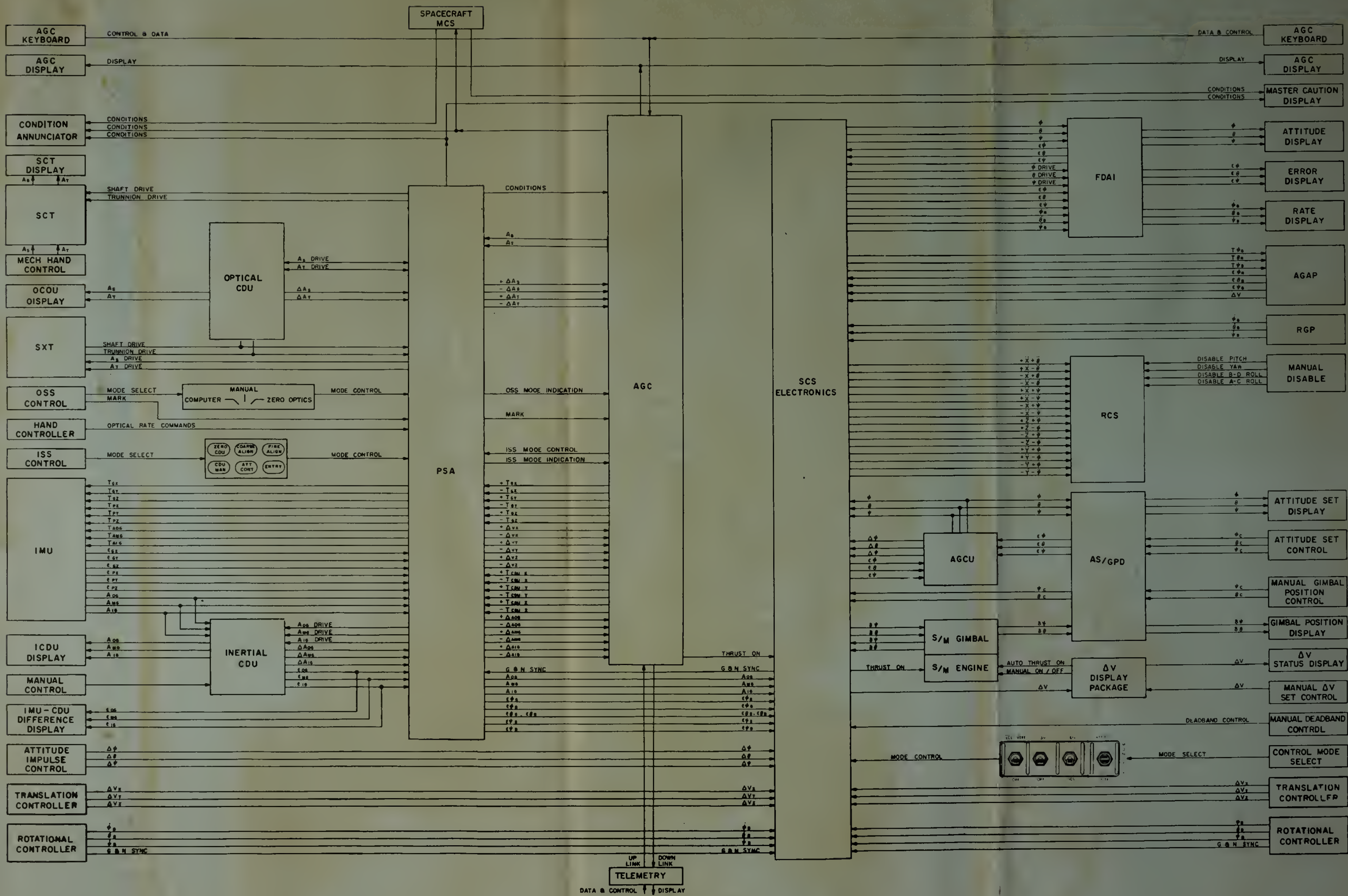


Figure A-3 Guidance, Navigation and Control System Block Diagram, Block I (Series 100)

LIST OF ABBREVIATIONS

ABBREVIATIONS	DEFINITIONS
AC	Alternating Current
ACE	Acceptance Checkout Equipment
ADA	Angular Differentiating Accelerometer
ADIA	Acceleration Along the IRIG Input Axis
ADSRA	Acceleration Along the IRIG Spin Reference Axis
AGC	Apollo Guidance Computer
AGE	Apollo Guidance and Navigation Equipment
AP	Aim Point
A_s	Shaft Angle (Optics)
A_t	Trunnion Angle (Optics)
BD	IRIG Bias Drift
CDU	Coupling Display Unit
CG	Center of Gravity
C&IS	Communications and Instrumentation System
CM	Command Module
CSM	Command and Service Module
CSS	Computer Subsystem
CTS	Computer Test Set
DAC	Digital to Analog Converter
DC	Direct Current
D & C	Display and Control
DSKY	Display and Keyboard
ECS	Environmental Control System
EPS	Electrical Power System
FDAI	Flight Director Attitude Indicator
G & N	Guidance and Navigation

ABBREVIATIONS	DEFINITIONS
GSE	Ground Support Equipment
IA	Input Axis
ICTC	Inertial Components Temperature Controller
IGA	Inner Gimbal Axis
IMU	Inertial Measurement Unit
IRIG	Inertial Reference Integrating Gyro
ISS	Inertial Subsystem
LOS	Line of Sight
LLOS	Landmark Line of Sight
MGA	Middle Gimbal Axis
MILA	Merritt Island Launch Area
MIT/IL	Instrumentation Laboratory of MIT
MSFN	Manned Space Flight Network
NAA	North American Aviation
NB	Navigation Base
OGA	Outer Gimbal Axis
OIA	Optics-Inertial Analyzer
OJB	Overhead Junction Box
OSS	Optical Subsystem
PCM	Pulse Code Modulated
PIP	Pulsed Integrating Pendulum
PIPA	Pulsed Integrating Pendulum Accelerometer
PSA	Power and Servo Assembly
RCS	Reaction Control System
SAT	Systems Assembly and Test
S/C	Spacecraft
SCS	Stabilization and Control System
SCT	Scanning Telescope

ABBREVIATIONS	DEFINITIONS
SLOS	Star Line of Sight
S/M	Service Module
SM	Stable Member (IMU)
SPS	Service Propulsion System
SXT	Sextant
S-1B	Stage 1 of the Saturn V Launch Vehicle
S-4B	Stage 3 of the Saturn V Launch Vehicle
UTS	Universal Test Station